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ERRATA

Page 4, Table 2, under Icy Strait: *North end of Chicagof Island* should read *North end of Chichagof Island.*

Page 5, Table 3, second line under Icy Strait: *Gul* should be *Gulf.*

Page 14, Table 11, eighth line: *C arence* should be *Clarence.*

Page 122, first paragraph, third line: *Spriodela* should be *Spirodela.*

Page 218, paragraph No. 12, last line: (*pp. 156 and 216*) should be inserted after the word *River.*

Page 305, third line from bottom: A comma should follow the word *depletion* at the end of the line.

SALMON-TAGGING EXPERIMENTS IN ALASKA, 1927 AND 1928[1]

By Willis H. Rich, Ph. D., *In charge, Pacific Coast Fishery Investigations*
Frederick G. Morton, *Warden, Alaska Fisheries Service*
U. S. Bureau of Fisheries

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INTRODUCTION

The series of salmon-tagging experiments in Alaska, which was begun in 1922, was continued during the two years covered by this report. In 1927 a number of experiments were conducted in southeastern Alaska and one in Uganik Bay, Kodiak Island. In 1928 an experiment was carried out at Nicholaski Spit on the Alaska Peninsula. The experiments in southeastern Alaska were designed to fill in some of the gaps in the information that had been secured from previous experiments in this district. The other experiments were designed to settle specific questions that had arisen in connection with the administration of the fisheries. Although many details of the salmon migrations yet remain to be discovered, it is our opinion that the general features are now well enough known so that there is little need to continue general tagging experiments of the nature of those performed in southeastern Alaska in 1924 to 1927. It is planned, therefore, to use the method of tagging in the future only in connection with specific problems, such as those at Uganik Bay and Nicholaski Spit, which are covered by this report.

The method of tagging and the results of the earlier experiments have been covered adequately in previous reports.[2] The experiments in southeastern Alaska in 1927 were conducted by the junior author, who also collected and tabulated the data.

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[1] Submitted for publication Mar. 8, 1929.

[2] Experiments in Tagging Adult Red Salmon, Alaska Peninsula Fisheries Reservation, Summer of 1922. By Charles H. Gilbert. Bulletin, U. S. Bureau of Fisheries, Vol. XXXIX, 1923–24 (1924), pp. 39–50, 1 fig. Washington, 1923. Second Experiment in Tagging Salmon in the Alaska Peninsula Fisheries Reservation, Summer of 1923. By Charles H. Gilbert and Willis H. Rich. *Ibid*, Vol. XLII, 1926 (1927), pp. 27–75, 12 figs. Washington, 1925. Salmon-Tagging Experiments in Alaska, 1924 and 1925. By Willis H. Rich. *Ibid*, pp. 109–146, 1 fig. Washington, 1926. Salmon-Tagging Experiments in Alaska, 1926. By Willis H. Rich and Arnie J. Suomela. *Ibid*, Vol. XLIII, 1927, Pt. II (1929), pp. 71–104, 17 figs. Washington, 1927.

The experiment at Uganik Bay was made by the senior author and that at Nicholaski Spit by L. G. Wingard, assistant agent, Alaska Fisheries Service.

SOUTHEASTERN ALASKA, 1927

These experiments were designed primarily to supplement the data secured in 1924, 1925, and 1926. While, in general, the results have merely confirmed those of previous experiments, it has seemed best to publish the data in full on account of the importance of corroborating our findings. It may be pointed out here that when the results of two or more entirely independent experiments run parallel the probability that they are valid is greater than in the case of a single experiment involving an equal number of individuals. Whenever the new data agree closely with those secured previously, the reader will merely be referred to the earlier reports, which contain adequate discussions that need not be repeated here.

Owing to the exceptionally light run and the late appearance of the fish in all districts, only 4,668 salmon were tagged during the entire season. Commencing in the Chatham Strait and Icy Strait districts, operations were moved gradually southward with the appearance of the fish. The salmon run in the southern district, however, proved to be exceptionally light, and only a few hundred fish were tagged in the vicinity of Gravina Island in Clarence Strait. In all districts the experiments showed the fishing gear to be working very efficiently, and in some instances more than 50 per cent of the fish tagged were recaptured. It was the policy of the bureau to tag the salmon when conditions were most favorable and, whenever possible, just prior to a weekly closed period, thereby giving the fish every opportunity to make headway on their course. A close watch was kept of the fish tagged, and at no time did they appear sluggish or linger around the scene of operations after they were liberated.

The two previous reports (Rich, 1926, and Rich and Suomela, 1927) contain maps showing the distribution of the tagged fish, and it has not seemed necessary to republish these maps here. Those reports also contain lists of minor localities not shown on the maps.

SUPPLEMENTARY LIST OF MINOR LOCALITIES FROM WHICH TAGGED SALMON WERE RECORDED

Abraham Island. Northern end of Clarence Strait near Etolin Island.
Ansley Point. Near eastern entrance to Icy Strait, northern shore.

Benita Passage. Lower end of Etolin Island, between Etolin and Stone Islands.
Big Johns Bay. Keku Strait.
Blashke Islands. Kashevarof Passage, northern end of Clarence Strait.
Bluff Point. Western arm of Behm Canal at the entrance to Yes Bay.
Boulder Point. Sumner Strait at southern entrance to Keku Strait.
Breakwater, North and South. Revillagigedo Channel, north of Cape Fox, about latitude 54° 50′.

Cedar Point. Western shore of Annette Island.
Clear Point. Northern point of entrance to Funter Bay, Lynn Canal.
Cosmos Cove. Baranof Island, Chatham Strait, latitude 55° 15′.
Cube, Point. Admiralty Island, Chatham Strait, latitude 57° 58′.

Decision, Cape. Southern end of Kuiu Island, Sumner Strait.
Deer Island. Ernest Sound, latitude 56° 05′.
Dry Bay. In Portage Bay, Frederick Sound.
Dry Point. Eastern shore of Stephens Passage, latitude 57° 37′.

Eagle Creek. Eastern shore of Prince of Wales Island, 1 mile south of Luck Point.
Eagle River. Bradfield Canal.
Ellis, Point. Chatham Strait, northern entrance to Tebenkof Bay.
Escape Point. Western arm of Behm Canal, latitude 55° 39′.

False Island. Cleveland Peninsula, Clarence Strait, below Niblack Point.
Frederick, Port. Icy Strait, Chichagof Island, longitude 135° 30′.

Grand Rapids. Stikine River.
Guard Island. Clarence Strait near northern entrance to Behm Canal.
Gull Point. Onslow Island, Clarence Strait, near the northern end.
Gypsum. Near North Passage Point, Chatham Strait.

Harrington, Point. Etolin Island, Clarence Strait.
Hepburn, Point. Admiralty Island, Chatham Strait, latitude 57° 57′.
Herbert, Port. Chatham Strait, Baranof Island, latitude 56° 25′.
Hollis. Western shore of Twelve Mile Arm, Kasaan Bay.

Inian Pass, North. Between Inian Islands and the mainland, Cross Sound.
Italio River. Near Yakutat.

Karheen Cove. Karheen Passage, between Hecata and Tuxekan Islands.
Kashevarof Passage. Northern end of Clarence Strait.
Kasnyku Bay. Chatham Strait, Baranof Island, latitude 57° 12′.
Ketchikan Creek. Entering Revillagigedo Channel at Ketchikan.
Kitchen Island. British Columbia. Exact location doubtful.
Kittens, The. Near Funter Bay, Chatham Strait.

Little Pybus Bay. Just south of Pybus Bay, Frederick Sound.

Mansfield Point. Same as Mansfield Peninsula, northern end of Admiralty Island.
March, Point. Southern end of Prince of Wales Island, eastern entrance to Cordova Bay.
Misery Island. Clarence Strait near Lemesurier Point.
Mole Harbor. In Seymour Canal.
Moonshine Point. Chatham Strait, near Point Caution, southern entrance to Hood Bay.

Nelson Point. Behm Canal, entrance to Smeaton Bay.

Peninsular Point. Chatham Strait just north of entrance to Peril Strait.
Pleasant Bay. Seymour Canal, Stephens Passage.
Portage Creek. Kake Harbor, Keku Strait.

Ratz Point. Clarence Strait, north end of Prince of Wales Island, latitude 55° 55′.
Red Bluff Bay. Chatham Strait, Baranof Island, latitude 56° 50′.

Saginaw Channel. Separating Shelter Island from Admiralty Island.
Salisbury Sound. At the western end of Peril Strait.
Selwyn Inlet. Queen Charlotte Islands, British Columbia.
Shelter Island. Saginaw Channel, southern end of Lynn Canal.
Ship Harbor. Clarence Strait, approximately latitude 55° 37′ and longitude 132° 12′.
Snipe Bay. Outer coast of Baranof Island, latitude 56° 25′.
Spacious Bay. Northern arm of Behm Canal near Yes Bay.
Square Cove. Chatham Strait near Cube Point.
St. John Point. Zarembo Island, Sumner Strait.

Three Islands. Clarence Strait, approximately latitude 55° 42′ and longitude 132° 14′.

Vandeput Point. Northern shore of Frederick Sound, longitude 133°.
Vegas Islands. Between Duke and Annette Islands, Clarence Strait.

Wolf Creek. Clarence Strait 3 miles north of Ship Island.
Woody Point. Admiralty Island, Chatham Strait, latitude 57° 15′.
Wrangell Island, south end. Ernest Sound.
Wright Sound. British Columbia, mainland, latitude 53° 20′.

The following table gives the data for the tags attached in southeastern Alaska during 1927:

TABLE 1.—*Tags attached in southeastern Alaska, 1927*

Experiment No.	Date	Serial Nos.	Species of fish tagged: Red	Pink	Chum	Coho	King	Locality
1	July 1	1–100	29	16	53		1	Parker Point, Chatham Strait.
2	July 9	101–400	32	107	158	2		Hourigan Point, Frederick Sound.
3	do	401–475	3	17	55			Carroll Island, Frederick Sound.
4	July 12	501–700	18	90	73	10	9	Marble Bluffs, Chatham Strait.
5	do	701–900	13	112	65	7	3	Parker Point, Chatham Strait.
6	July 14	901–1200	40	212	15	33		Inian Islands, Icy Strait.
7	July 16	1201–1700	101	362	8	27		Pleasant Island, Icy Strait.
8	do	1701–1900	10	186	3	1		Inian Islands, Icy Strait.
9	July 19	1901–2300	20	164	189	27		Hourigan Point, Frederick Sound.
10	July 20	2301–2800	30	347	98	21	3	Cape Bendel, Frederick Sound.
11	July 21	2801–3000	28	115	40	17		Point Hobart, Stephens Passage.
12	July 26	3001–3500	198	271	4	26	1	Point Colpoys, Sumner Strait.
13	July 30	3501–4000	185	306	6	2		Do.
14	do	4001–4300	29	164	82	24		Cape Decision, Sumner Strait.
15	Aug. 5	4301–4450	7	86	51	6		Dall Head, Gravina Island.
16	Aug. 6	4451–4700	4	240	1	5		Nelson Cove, Gravina Island.

RETURNS FROM EXPERIMENTS IN ICY STRAIT

RED SALMON

One hundred and fifty-one red salmon were tagged in Icy Strait during 1927, 41 of which were recaptured (27.1 per cent). The data are presented in Table 2.

TABLE 2.—*Returns from red salmon tagged in Icy Strait, 1927*

[In this and subsequent tables the figures in the columns headed "Days" represent the least and the greatest time that elapsed between tagging and reported recapture. The figures in the columns headed "Number" represent the number of fish recaptured in the given locality]

Locality of recapture	Locality and date of tagging: Inian Islands, July 14: Number	Inian Islands, July 14: Days	Inian Islands, July 16: Number	Inian Islands, July 16: Days	Pleasant Island, July 16: Number	Pleasant Island, July 16: Days	Total number recaptured
Icy Strait:							
No details	1	6					1
Dundas Bay	1	9					1
Gull Cove	1	5					1
Pleasant Island					1	6	1
Point Adolphus					1	7	1
East of Porpoise Islands	1	4			1	2	2
Hoonah					1	4	1
West of Rocky Island					1	4	1
North end of Chicagof Island					1	9	1
Lynn Canal:							
Douglas Island					1	4	1
Naked Island					1	9	1
Tee Harbor					1	10	1
Chatham Strait:							
Mansfield Point					1	7	1
South of Clear Point					1	6	1
North of Hawk Inlet					4	1–5	4
Hawk Inlet	2	5–6			1	1	3
Square Cove					2	4–5	2
South of Passage Point					2	4–5	2
Marble Bluffs					2	7–9	2
Basket Bay			1	7	1	4	2
Distant Point			1	15			1
Village Point					1	6	1
Near Kingsmill Point	1	23					1
Peril Strait: Hooniah Sound					1	19	1
Frederick Sound: Deepwater Point					1	8	1
Stephens Passage: Snettisham Inlet	1	10			3	4	4
Snipe Bay	1	42					1
West Coast Prince of Wales Island: Nichols Bay	1	37					1
Total	10		2		29		41
Percentage returned	40		20		18.1		27.1

Previous experiments had shown that the red-salmon runs entering Icy Strait early in the season (the latter part of June) contained fish bound for the Chilkat and Chilkoot Rivers. Later in the season (July 24 to 29) the Chilkat and Chilkoot fish appear to be gone, but Taku River fish appear in appreciable numbers. The Icy Strait experiments of 1927 were designed to test the distribution of the run at an intermediate period. The results are similar to those obtained from the experiments of July 24 to 29, 1926 (Rich and Suomela, p. 94), and indicate that the Chilkat and Chilkoot fish have passed through Icy Strait by the middle of July. There is, however, a relatively large migration south into Chatham Strait, and in this respect the experiments of 1927 resemble those of the latter part of June, 1926. (Rich, p. 119.)

PINK SALMON

Seven hundred and sixty pink salmon werê tagged in Icy Strait during 1927, of which 287 were recaptured (37.7 per cent). The data are presented in Table 3.

TABLE 3.—*Returns from pink salmon tagged in Icy Strait, 1927*

Locality of recapture	Locality and date of tagging						Total number recaptured
	Inian Islands				Pleasant Island, July 16		
	July 14		July 16				
	Number	Days	Number	Days	Number	Days	
Cross Sound:							
George Island	1	2					1
North of Inian Pass	1	5					
Inian Pass			1	6			1
Dundas Bay	1	5					1
Icy Strait:							
No details	4	2–11	2	4	3	4–20	9
Gul Cove					2	3	2
Point Gustavus					2	3–5	2
East of Point Gustavus					1	3	1
Pleasant Island	7	1–5	3	2–9	8	2–4	18
Point Adolphus	6	2–30	3	4–7			9
Eagle Point	1	7	6	3	5	5–12	12
West of Rocky Island	2	3–5	2	4–6	2	4–5	6
East of Porpoise Islands					4	2–16	4
Ansley Point	4	6–11	2	4–5	3	4	9
North end of Chichagof Island					1	9	1
Hoonah			1	6			1
Port Frederick					2	21	2
Point Sophia					1	4	1
Point Augusta	1	6	3	4	6	4	10
Lynn Canal:							
South of Point Retreat					4	6–13	4
Tee Harbor	1	6			3	4	4
Douglas Island	1	6	1	4			2
Shelter Island					2	4	2
Shelter Cove					1	10	1
Chatham Strait:							
The Kittens	1	3			3	3–11	4
South of Clear Point			1	13	2	13–22	3
Mansfield Point	3	4	5	4–9	3	2–4	11
North of Hawk Inlet	7	2–17	3	3–9	9	1–10	19
Hawk Inlet	3	3–6	3	3–7	11	1–11	17
Point Marsden					2	1–11	2
Square Cove			4	4–7	5	4–5	9
Cube Point			1	9	3	4–7	4
Point Hepburn	1	8	1	4	4	6	6
False Bay					1	4	1
Gypsum			1	12	1	12	2
Fishery Point	1	28	1	26	2	26	4
Marble Bluffs			4	7–10	4	7–9	8
South of Passage Point	2	7	4	4–22	9	4–15	15
Basket Bay	1	8	1	15	1	7	3
Peninsular Point	1	6			1	4	2
Woody Point			2	4–6	1	6	3
Hood Bay					1	3	1
Distant Point	2	8–9			2	7–15	4
Village Point	2	6–9	3	4–7	6	4–8	11
Point Caution	4	5–7	3	11–13			7
Moonshine Point			1	12	1	2	2
Rocky Bay	3	6–25					3
Kingsmill Point	2	6–10			2	6–20	4

TABLE 3.—*Returns from pink salmon tagged in Icy Strait, 1927*—Continued

Locality of recapture	Locality and date of tagging						Total number recaptured
	Inian Islands				Pleasant Island, July 16		
	July 14		July 16				
	Number	Days	Number	Days	Number	Days	
Peril Strait:							
No details			1	13	2	13–19	3
Rodman Bay	1	15					1
Frederick Sound:							
Carroll Island			1	6			1
Deepwater Point					2	8–12	2
Pybus Bay			1	23			1
Cape Bendel			1	19			1
Fanshaw Bay					1	14	1
Stephens Passage:							
Point Hobart					1	10	1
Windham Bay			1	17	2	9–16	3
Seymour Canal					3	13–17	3
Mole Harbor					1	5	1
Shoal Point			1	12	2	12	3
Snettisham Inlet					2	4–19	2
Limestone Inlet			1	11			1
Taku Inlet	1	15			1	13	2
Taku River	2	6–14	1	6	1	7	4
Groundhog Bay			3	4–5	1	5	4
Slocum Arm	1	12					1
Salisbury Sound					1	8	1
Karheen					1	35	1
Total	68		73		146		287
Percentage returned	31.6		39.2		40.3		37.7

The results are, in every important respect, the same as those secured from the previous experiments, indicating that the main route of migration is south into Chatham Strait and Frederick Sound.

CHUM SALMON

Twenty-six chum salmon were tagged in Icy Strait during 1927, five of which were recaptured (19.2 per cent). One was taken in Icy Strait, two in Chatham Strait, and two in Stephens Passage. These results, although few, agree with the earlier experiments.

COHO SALMON

Sixty-one coho salmon were tagged in Icy Strait during 1927, 11 of which were recaptured (18 per cent). The data are presented in Table 4. The results again corroborate the earlier experiments, showing the chief route of migration to be into Chatham Strait. It is also to be noted that the relatively slow migration of cohos is again shown clearly.

TABLE 4.—*Returns from coho salmon tagged in Icy Strait in 1927*

Locality of recapture	Locality and date of tagging				Total number recaptured
	Inian Islands, July 14		Pleasant Island, July 16		
	Number	Days	Number	Days	
Cross Sound: Inian Islands	1	60			1
Italio River, Yakutat	1	47			1
Chatham Strait:					
Mansfield Point			1	4	1
Point Cube			1	13	1
Marble Bluffs			1	19	1
Village Point			2	4–7	2
Point Caution			1	29	1
Chatham Strait—Continued.					
Wilson Cove			1	26	1
Cosmos Cove			1	25	1
Baranof Island: Snipe Bay			1	42	1
Total	2		9		11
Percentage returned	6		33.3		18

RETURNS FROM EXPERIMENTS IN CHATHAM STRAIT

RED SALMON

Sixty red salmon were tagged in Chatham Strait during 1927, 15 of which were recaptured (25 per cent). The data are presented in Table 5 and are very similar to those secured in 1926: Both series indicate migrations both north and south from the point of tagging. In the experiments of 1924 and 1925 red salmon were tagged in Chatham Strait south of Frederick Sound. None of these fish were taken in Chatham Strait north of Frederick Sound, and yet both the experiments of 1926 and 1927 indicate a migration north from the region of Parker Point and Marble Bluffs. These facts may indicate that a considerable run of salmon enters southeastern Alaska through Peril Strait.

TABLE 5.—*Returns from red salmon tagged in Chatham Strait, 1927*

Locality of recapture	Locality and date of tagging						Total number re-captured
	Parker Point				Marble Bluffs, July 12		
	July 1		July 12				
	Number	Days	Number	Days	Number	Days	
Chatham Strait, north of Parker Point:							
South of Passage Point			1	3			1
Fishery Point					1	3	1
Hawk Inlet	1	2					1
North of Hawk Inlet			2	2–5	1	2	3
Icy Strait					1	5	1
Lynn Canal: Point Retreat	1	12					1
Chatham Strait, south of Parker Point:							
Basket Bay	1	7			1	12	2
Village Point					1	10	1
Stephens passage:							
Snettisham Inlet			1	18			1
Taku Inlet	1	26					1
Taku River					1	3	1
Stikine River: North Arm [1]					1	(?)	1
Total	4		4		7		15
Percentage returned	13.7		30.7		38.8		25

[1] Reported captured before date of tagging.

PINK SALMON

Two hundred and eighteen pink salmon were tagged in Chatham Strait during 1927, 70 of which were recaptured (32.1 per cent). The data are presented in Table 6. They corroborate the data secured in 1926 but add nothing new.

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Table 6.—*Returns from pink salmon tagged in Chatham Strait, 1927*

Locality of recapture	Locality and date of tagging						Total number re-captured
	Parker Point				Marble Bluffs, July 12		
	July 1		July 12				
	Number	Days	Number	Days	Number	Days	
Chatham Strait, north of Parker Point:							
Peninsular Point			1	3			1
Marble Bluffs			2	1–3	7	1–16	9
Fishery Point			1	30	4	3	5
Cube Point					1	4	1
Point Hepburn			1	4	2	2	3
Hawk Inlet	1	13	2	3	2	3	5
North of Hawk Inlet	1	4	1	2	1	4	3
Icy Strait:							
West of Rocky Island			2	5	1	8	3
East of Porpoise Island					1	6	1
Point Adolphus					1	10	1
Lynn Canal:							
The Kittens			1	5			1
Naked Island					1	1	1
Douglas Island	1	7	1	8			2
Chatham Strait, south of Parker Point:							
Parker Point			7	3–16			7
Basket Bay			3	3–4			3
Morris Reef			1	3			1
Distant Point			1	22			1
Woody Point			1	9			1
Point Caution			5	2	1	16	6
Moonshine Point			1	2			1
Cosmos Cove			1	1			1
Kingsmill Point			2	8–34			2
Frederick Sound:							
Hourigan Point					1	9	1
Point Macartney			1	2			1
Stephens Passage:							
Point Hobart			1	10			1
Seymour Canal			4	8–17			4
Mole Harbor			2	9–14			2
Snettisham Inlet			1	17			1
Taku Inlet					1	8	1
Total	3		43		24		70
Percentage returned	18.7		38.3		26.6		32.1

CHUM SALMON

One hundred and ninety-one chum salmon were tagged in Chatham Strait during 1927, 64 of which were recaptured (33.5 per cent). The data are presented in Table 7.

Table 7.—*Returns from chum salmon tagged in Chatham Strait, 1927*

Locality of recapture	Locality and date of tagging						Total number re-captured
	Parker Point				Marble Bluffs, July 12		
	July 1		July 12				
	Number	Days	Number	Days	Number	Days	
Chatham Strait, north of Parker Point:							
Marble Bluffs			2	2–16	4	1–16	6
Basket Bay	3	1–14	3	8–14	4	3–14	10
South of Passage Point	1	14					1
Fishery Point			1	3			1
Gypsum					1	13	1
Cube Point	1	13					1
Hawk Inlet	2	4					2
Point Augusta					1	3	1
Icy Strait:							
No details					1	24	1
Ansley Point			1	4			1
Point Adolphus			2	3–10	1	6	3

TABLE 7.—*Returns from chum salmon tagged in Chatham Strait, 1927*—Continued

Locality of recapture	Locality and date of tagging						Total number recaptured
	Parker Point				Marble Bluffs, July 12		
	July 1		July 12				
	Number	Days	Number	Days	Number	Days	
Lynn Canal:							
Naked Island			1	3	1	4	2
Douglas Island	3	7–12					3
Chatham Strait, south of Parker Point:							
Parker Point			1	14	1	3	2
Hood Bay			3	6–9	2	6	5
Woody Point			1	9			1
Distant Point					2	15–22	2
Rocky Point					1	2	1
Point Caution	2	8–20	1	2	1	4	4
Kingsmill Point	1	5			1	7	2
Peril Strait					1	17	1
Salisbury Sound					1	4	1
Frederick Sound:							
Carroll Island			1	24			1
Point Brightman					2	8–13	2
Hourigan Point					1	9	1
Cape Fanshaw			1	10			1
Stephens Passage:							
Port Houghton	1	6					1
Seymour Canal	2	19–34					2
Mole Harbor					1	9	1
Windfall Harbor					1	12	1
Dry Bay	1	20					1
Taku River					1	7	1
Total	17		18		29		64
Percentage returned	32.1		27.6		39.7		33.5

Very few chums were tagged in previous experiments at this point, so that the information contained in the table is virtually all new. The distribution of this species is, however, very similar to that of the pinks. Two important routes of migration are shown. The main migration followed a northerly route through Chatham Strait to its junction with Icy Strait, from whence four returns were reported. The southerly migration showed a tendency to follow the Admiralty Island shore of Chatham Strait to Frederick Sound, where five tagged fish were recaptured. One individual crossed Frederick Sound and was recaptured at Hourigan Point on the Kuiu Island shore. Seven returns were reported from Stephens Passage, of which four were recaptured in Seymour Canal. One individual was reported from Peril Strait and another from Salisbury Sound.

COHO SALMON

Seventeen coho salmon were tagged in Chatham Strait at Marble Bluffs and Parker Point during 1927, of which three were recaptured (17.6 per cent). One each was reported from the following localities: North of Hawk Inlet, Chatham Strait, 2 days; Marble Bluffs, Chatham Strait, 3 days; Point Gardner, Chatham Strait, 56 days.

KING SALMON

Thirteen king salmon were tagged in Chatham Strait at Marble Bluffs and Parker Point during 1927, two of which were recaptured (15.3) per cent, one each from the following localities: Wilson Cove, Chatham Strait, 29 days; Point Adolphus, Icy Strait, 10 days.

RETURNS FROM EXPERIMENTS IN FREDERICK SOUND

Four tagging experiments were made here in 1927, the greater number of the tagged fish being pinks and chums. Two hundred and ninety-nine fish were tagged at Hourigan Point on July 1, 75 at Carroll Island on July 9, 400 at Hourigan Point on July 19, and 499 at Cape Bendel on July 20. Although there are some distinct differences in the results obtained from these experiments, the general similarities are sufficient to warrant considering them together.

RED SALMON

Only 14 fish of this species were recaptured, and no important additions were made to our previous knowledge of their migration. Four of those tagged near the western end of Frederick Sound were taken later in Chatham Strait. One was taken in Clarence Strait, one in the Stikine River at Grand Rapids, and the other eight in Frederick Sound and Stephens Passage.

PINK SALMON

Six hundred and thirty-five pink salmon were tagged in Frederick Sound and 307 (48.4 per cent) were recaptured later. The data are presented in Table 8.

TABLE 8.—*Returns from pink salmon tagged in Frederick Sound, 1927*

Locality of recapture	Locality and date of tagging								Total number recaptured
	Hourigan Point				Carroll Island July 9		Cape Bendel July 20		
	July 9		July 19						
	Number	Days	Number	Days	Number	Days	Number	Days	
Frederick Sound:									
Hourigan Point			5	2–20			2	1–10	7
Security Bay							1	10	1
Saginaw Bay			2	9–22			1	8	3
Carroll Island			1	1					1
Herring Bay			2	10			4	7–9	6
Point Highland	1	7	4	18			4	1–19	9
Deepwater Point	1	32	10	5			19	1–21	30
Point Macartney	4	5–7	5	2–9			5	1–17	14
Cape Bendel			4	3–6			8	2–16	12
Little Pybus Bay	1	20	1	10			3	9–18	5
Pybus Bay	1	6	1	6			4	2–37	6
Point Pybus			1	10			3	4–5	4
Keku Strait							1	21	1
Cape Fanshaw	3	3	8	2–18			24	1–15	35
Fanshaw Bay			3	4–9			10	2–8	13
Dry Bay			2	18			2	5–14	4
Point Vandeput			1	7					1
Cape Strait							1	21	1
Thomas Bay							1	1	1
Chatham Strait, north of Frederick Sound:									
No details							1	19	1
Kasnyku Bay			1	17					1
Rocky Bay							2	8–23	2
Peril Strait	1	20					2	7–15	3
Point Caution	1	3	1	5			1	8	3
Cosmos Cove			1	5			1	9	2
Distant Point							2	13	2
Hood Bay	1	10							1
Basket Bay			1	9					1
Marble Bluffs	1	4					1	16	2
Cube Point							1	5	1
Point Marsden			1	19					1
Hawk Inlet			2	3–4					2
Funter Bay	1	11							1
Icy Strait: West of Rocky Island							1	6	1
Chatham Strait, south of Frederick Sound:									
Kingsmill Point	11	2	2	4–8					13
South of Kingsmill Point			11	1–20			2	2–4	13
North of Washington Bay			4	1–9			3	5–13	
Tebenkof Bay	1	5							

TABLE 8.—*Returns from pink salmon tagged in Frederick Sound, 1927*—Continued

Locality of recapture	Locality and date of tagging								Total number recaptured
	Hourigan Point				Carroll Island July 9		Cape Bendel July 20		
	July 9		July 19						
	Number	Days	Number	Days	Number	Days	Number	Days	
Stephens Passage:									
Port Houghton	2	13–30	4	5–23			5	2–15	11
Point Hobart			1	10			1	5	2
Hobart Bay							2	9–10	2
Windham Bay			3	5–19	1	6	13	4–17	17
Seymour Canal	7	7–13	7	1–18	2	11–20	20	1–22	36
Mole Harbor	2	10–13			1	10	4	6	7
Windfall Harbor	2	11–18					3	7	5
Pleasant Bay	1	19					2	3–8	3
Limestone Inlet	1	4	2	15			1	14	4
Taku River							1	(?)	1
Shelter Cove							1	5	1
Salisbury Sound			1	5			1	4	2
Clarence Strait:									
Snow Passage							1	14	1
McNamara Point	1	20							1
Ernest Sound: Watkins Point							1	11	1
West Coast Prince of Wales Island: Karheen							1	31	1
Total	44		92		4		167		307
Percentage returned	41.1		56.0		23.5		48.2		48.4

These data fully confirm the results of previous experiments in showing that the pinks of Frederick Sound are distributed chiefly among the streams of that locality and Stephens Passage. Virtually every experiment, however, has shown a slight movement out of the sound and both north and south in Chatham Strait. No new facts of importance were brought out by the tagging experiments of 1927.

CHUM SALMON

Five hundred chum salmon were tagged in Frederick Sound during 1927, of which 117 were recaptured later. The data are presented in Table 9.

TABLE 9.—*Returns from chum salmon tagged in Ferderick Sound, 1927*

Locality of recapture	Locality and date of tagging								Total number recaptured
	Hourigan Point				Carroll Inlet, July 9		Cape Bendel July 20		
	July 9		July 19						
	Number	Days	Number	Days	Number	Days	Number	Days	
Frederick Sound:									
Hourigan Point			3	1–11					3
Security Bay	4	10–26	11	4–15			1	10	16
Herring Bay			2	10			1	6	3
Deepwater Point	1	15	3	2–16	1	15	1	(?)	6
Big Johns Bay	3	19–21	4	10–23			1	11	8
Keku Strait	2	18–22	4	12–25			1	21	7
Kake Harbor			1	10					1
Portage Creek, Kake			1	16					1
Point Macartney			1	2			2	4–9	3
Cape Bendel					1	21			1
Little Pybus Bay	1	27					2	9	3
Pybus Bay			1	22					1
Fanshaw Bay			1	9					1
Cape Fanshaw			2	13–21			1	9	3
Chatham Strait, north of Frederick Sound:									
Point Gardner					1	33			1
Point Caution	2	20	1	12			1	17	4
Cosmos Cove			1	7					1
Distant Point			3	3–4					3

TABLE 9.—*Returns from chum salmon tagged in Frederick Sound, 1927*—Continued

Locality of recapture	Locality and date of tagging								Total number recaptured
	Hourigan Point				Carroll Inlet, July 9		Cape Bendel, July 20		
	July 9		July 19						
	Number	Days	Number	Days	Number	Days	Number	Days	
Chatham Strait, north of Frederick Sound—Con.									
Hood Bay			1	7					1
Basket Bay							1	11	1
Hawk Inlet							1	6	1
Chatham Strait, south of Frederick Sound:									
Kingsmill Point	5	2–10			2	2–9			7
South of Kingsmill Point			4	1–32					4
North of Washington Bay			3	9–10			1	(?)	4
Bay of Pillars			3	8–24					3
Tebenkof Bay	1	13	6	3–13			1	7	8
Stephens Passage:									
Port Houghton	1	26							1
Gambier Bay			1	10					1
Seymour Canal	4	11–16			1	33	2	8–13	7
Mole Harbor					1	20			1
Windfall Harbor	1	18					1	7	2
Pleasant Bay			1	9					1
Limestone Inlet							1	10	1
Windham Bay			1	7			1	10	2
Shelter Cove			1	6					1
Sumner Strait:									
Calder Bay					1	33			1
Karheen			1	31					1
Stikeen River	1	25							1
Point McNamara, Clarence Strait			1	15					1
Breakwater, North, Revillagigedo Channel	1	17							1
Total	27		62		8		20		117
Percentage returned	17.1		32.8		14.5		20.4		23.4

These data provide new information relative to the migration of chum salmon taken in Frederick Sound, as comparatively few chums had been tagged here in the previous experiments. The main migration of chum salmon tagged at Hourigan Point and Carroll Island traversed Frederick Sound to its junction with Stephens Passage, thence northerly, where 12 returns are shown from various points in Stephens Passage. Nine returns are reported from Chatham Strait north of Kingsmill Point and 24 from Chatham Strait south of that point. Two returns are shown from Sumner Strait and one from Stikine River. One was reported at McNamara Point, Clarence Strait, and another individual was recaptured at North Breakwater in Revillagigedo Channel.

The returns from the chums tagged at Cape Bendel, Frederick Sound, show two distinct migrations. The main migration followed through Frederick Sound, particularly along the Admiralty Island shore, to its junction with Chatham Strait, from whence three of the fish took a northerly route extending as far north in Chatham Strait as Hawk Inlet. Two followed the Kuiu Island shore of Chatham Strait and were recaptured north of Washington Bay and in Tebenkof Bay, respectively. The other important migration was into Stephens Passage, from which place one-fourth of the returns were secured.

COHOS

Fifty cohos were tagged and nine were recaptured later. Five were taken in Frederick Sound and Stephens Passage; 2 in Chatham Strait; 1 in Clarence Strait; and 1 in Selwyn Inlet, Queen Charlotte Islands, British Columbia.

RETURNS FROM EXPERIMENTS AT POINT HOBART, STEPHENS PASSAGE

Two hundred salmon were tagged at Point Hobart, Stephens Passage, on July 21. Of this number 28 were reds, 115 pinks, 40 chums, and 17 cohos. None of the cohos were returned. Five red salmon were recaptured (17.8 per cent). Two of these were taken at Snettisham, Stephens Passage, one in 2 and the other in 9 days; two others were taken in Herring Bay, Frederick Sound; one in 2 and the other in 8 days; and one was reported taken in Icy Strait after an interval of 7 days. Seven chums were recaptured (17.5 per cent). Three were taken in Stephens Passage, three in Frederick Sound, and one at Point Ellis, Chatham Strait.

PINK SALMON

The returns from pinks tagged at Point Hobart, Stephens Passage, are shown in Table 10 and indicate two distinct migrations. The heaviest of these was in a northerly direction into the waters of Stephens Passage. More than half of the returns from this migration were from Seymour Canal. The second and lighter migration was through Frederick Sound, both south and west from Point Hobart. One individual was recaptured in Basket Bay, Chatham Strait. This is an interesting addition to our knowledge of the salmon migrations in southeastern Alaska, as no experiments had been conducted previously in the southern part of Stephens Passage. It is evident that most of the fish taken in this region belong in Stephens Passage and doubtless have entered through Frederick Sound. The fish that went westward from Point Hobart may possibly have come down Stephens Passage from the north, but it seems much more probable that this movement represents more or less chance wandering of fish that are still feeding.

TABLE 10.—*Returns from pinks tagged at Point Hobart, July 21—115 tagged, 42 returns (36.5 per cent)*

Locality of recapture	Number	Days	Locality of recapture	Number	Days
Stephens Passage:			Frederick Sound:		
Point Hobart	2	1–3	Fanshaw Bay	1	2
Port Houghton	2	3–14	Cape Fanshaw	4	3–8
Hobart Bay	1	3	Point Pybus	1	5
Windham Bay	10	3–7	Pybus Bay	4	4
Mole Harbor	1	5	Deepwater Point	2	3
Pleasant Bay	1	2	Point Macartney	1	8
Seymour Canal	6	1–20	Saginaw Bay	1	7
Twin Point	1	3	Chatham Strait: Basket Bay	1	7
Snettisham	1	5			
Shoal Point	1	11			
Limestone Inlet	1	17			

RETURNS FROM EXPERIMENTS AT POINT COLPOYS, SUMNER STRAIT

RED SALMON

Three hundred and eighty-three salmon were tagged at Point Colpoys, Sumner Strait, on July 26 and 30, 118 of which were recaptured (30.8 per cent). The data are presented in Table 11. They support in detail the conclusions reached through the previous experiments but add nothing new to our knowledge of the migrations in this region.

TABLE 11.—*Returns from red salmon tagged at Point Colpoys, 1927*

Locality of recapture	Locality (Point Colpoys) and date of tagging				Total number recaptured
	July 26		July 30		
	Number	Days	Number	Days	
Sumner Strait:					
Point Colpoys	9	6–25	3	4	12
Red Bay	5	3			5
Point Baker			1	6	1
Stikine Flats	1	(1)			1
Frederick Sound: Boulder Point	1	10			1
Clarence Strait, north of Ernest Sound:					
Snow Passage	1	15			1
Point Nesbitt	5	3–6	2	7–14	7
West entrance, Stikine Strait			1	4	1
Etolin Island			1	5	1
Point Harrington	1	3			1
Marsh Island	1	2			1
Kashevarof Passage	1	3			1
Coffman Island			3	3–5	3
Whale Passage	3	2	3	3	6
Screen Islands	2	3–4			2
Eagle Creek	3	4–14	1	20	4
Ratz Point	2	3–12	3	4	5
Narrow Point	1	5	5	4–8	6
Ernest Sound:					
Union Bay	1	5	1	15	2
Eton Point			1	8	1
Watkins Point	1	5			1
Seward Passage			1	8	1
South end Wrangell Island	1	8			1
Bradfield Canal: Eagle River	1	4			1
Clarence Strait, south of Ernest Sound:					
Lemesurier Point			1	11	1
Meyers Chuck			1	3	1
Tolstoi Bay	2	4			2
Clarence Strait, South of Ernest Sound—Continued.					
Wolf Creek	1	5			1
Ship Island	2	8–10	2	6	4
Ship Harbor	1	10			1
False Island			1	5	1
Caamano Point			2	4–10	2
Grindall Point	1	10			1
Clover Passage	1	8			1
Guard Islands			1	14	1
Gravina Island	1	11	1	10	2
Dall Head	1	6			1
Cedar Point			1	5	1
Driest Point			1	13	1
Point Davison	2	4–12	1	6	3
Hotspur Island			2	8–13	2
Point Percy			3	4–7	3
Sealed Passage	1	8	1	6	2
Ingraham Bay			1	10	1
South Kendrick Bay	1	4			1
Cape Chacon			1	12	1
Cordova Bay: Point Marsh	1	23			1
Behm Canal: Yes Bay			1	55	1
Revillagigedo Channel:					
Kirk Point	1	14			1
Boat Harbor			2	5–10	2
Kanagunut Island			1	3	1
British Columbia:					
Portland Inlet	1	9			1
Mouth of Skeena River	1	8	1	2	2
Kitchen Island	1	6			1
Smith Island	1	6			1
Skeena or Nass Rivers [2]			7	(?)	7
Total	60		58		118
Percentage returned	30.3		31.3		30.8

[1] Reported captured before date of tagging.
[2] 7 tags recovered near Skeena River, Nass River, and Lowe Inlet, British Columbia, July and August.

PINK SALMON

Five hundred and seventy-seven pink salmon were tagged at Point Colpoys, Sumner Strait, during 1927, 232 of which were recaptured (40.2 per cent). The data presented in Table 12 show the same general distribution of pink salmon from Sumner Strait as was shown by the previous experiments. It is interesting to note, however, that none of the fish tagged in 1927 were recaptured on the west coast of Prince of Wales Island. This agrees with the experiments of 1926, but both differ in this respect from the experiments of 1924 and 1925, which were made at Ruins Point. It is evident that the fish that enter the strait as far as Point Colpoys are pursuing a definite migration, while those as far out as Ruins Point may or may not be definitely entering Sumner Strait.

TABLE 12.—*Returns from pink salmon tagged at Point Colpoys, 1927*

Locality of recapture	Locality (Point Colpoys) and date of tagging				Total number recaptured
	July 26		July 30		
	Number	Days	Number	Days	
Sumner Strait:					
Point Colpoys	3	6–13	5	2–6	8
Red Bay	1	3			1
Point St. John			1	1	1
Cape Decision			1	5	1
Barrier Islands	1	3			1
Frederick Sound: Hobart Bay	1	4			1
Clarence Strait:					
McNamara Point			2	4–6	2
Snow Passage	1	15	2	6–11	3
Point Nesbitt	4	3–6	2	8–9	6
West entrance to Stikine Strait	3	10–17			3
Point Harrington	1	3			1
Screen Islands	4	3–9	1	4	5
Point Barnes	2	3	1	7	3
Marsh Island	1	2			1
Abraham Islands	2	7–9			2
Whale Passage	3	2–3	2	3	5
Coffman Island			2	3–5	2
Eagle Creek	2	3–14			2
Benita Passage			1	4	1
Rocky Bay			1	3	1
Ratz Point			4	4–18	4
Gull Point	1	7			1
Onslow Island	3	7–12	1	3	4
Narrow Point	2	5	1	5	3
Ernest Sound:					
Union Bay	1	14	4	5	5
Union Point	6	1–5	8	3–10	14
Vixen Inlet	1	7	1	3	2
Eaton Point	7	5–12	7	3–19	14
Watkins Point	4	5–10	6	4–14	10
West side of Deer Island	1	8			1
Seward Passage	6	7–12	6	3–8	12
South end of Wrangell Island	14	5–8	6	5–10	20
Point Warde	1	8	3	4–7	4
Anan Creek	4	4–15	1	6	5
Clarence Strait, south of Ernest Sound:					
Lemesurier Point			1	5	1
Meyers Chuck			6	2–11	6
Misery Island	5	4			5
Three Islands	2	4–7	3	3–13	5
Clarence Strait, South of Ernest Sound—Continued.					
Wolf Creek	2	5	1	7	3
2 miles north of Ship Island			1	10	1
Tolstoi Bay	1	4			1
Ship Island			5	4–10	5
False Island	2	7–9	4	6–10	6
Caamano Point	3	8	4	4–8	7
Behm Canal:					
Betton Island	1	15	1	11	2
Point Higgins			1	7	1
Helm Bay			1	6	1
Traitors Cove			2	7–12	2
Clarence Strait south of Behm Canal:					
Island Point			1	14	1
Skin Island			1	10	1
Grant Cove	1	12			1
Nelson Cove	1	12			1
Gravina Island	1	17	3	4–7	4
Dall Head			3	8	3
Cedar Point			1	5	1
Point Davison			1	6	1
Hotspur Island			1	4	1
Vegas Islands	2	16	1	12	3
Sealed Passage	2	8			2
Duke Island			1	6	1
Cape Chacon			2	12	2
Nichols Passage: Bostwick Inlet			3	10–16	3
Revillagigedo Channel:					
Crab Bay			1	13	1
Point Sykes			1	10	1
Breakwater, south	1	10			1
Kah Shakes Point	1	4			1
Foggy Bay			1	6	1
Boat Harbor	2	12	1	5	3
Cape Fox	1	9			1
British Columbia:					
Nass River			1	8	1
Wright Sound			1	43	1
Total	108		123		231
Percentage returned	39. 8		40. 5		40. 2

COHO SALMON

Twenty-eight coho salmon were tagged at Point Colpoys, Sumner Strait, during 1927, six of which were recaptured (21.4 per cent). One was taken at Point Colpoys after 18 days, and the others were taken in various localities in Clarence Strait after 8 to 17 days.

RETURNS FROM EXPERIMENTS AT CAPE DECISION, SUMNER STRAIT

Two hundred and ninety-nine salmon were tagged at Cape Decision, Sumner Strait, on July 30. Of this number 29 were reds, 164 pinks, 82 chums, and 24 cohos.

RED SALMON

Of the 29 reds tagged at Cape Decision on July 30 only 4 were recaptured. One was taken in each of the following localities: Barrier Islands, Sumner Strait, 12 days; Tebenkof Bay, Chatham Strait, 11 days. Two were taken in or near the Skeena and Nass Rivers and Lowe Inlet, British Columbia, during July and August, but no definite dates or locations were recorded.

PINK SALMON

The returns from pinks tagged at Cape Decision, Sumner Strait, are presented in Table 13. These data would indicate two important migrations. The main migration traversed the waters of Sumner Strait to its junction with Clarence Strait, thence southerly in Clarence Strait. Two individuals of this migration were recaptured in Ernest Sound. One return is noted from Skeena River, British Columbia. The second and minor migration was northerly into Chatham Strait, whence 16 returns are reported.

TABLE 13.—*Returns from pinks tagged at Cape Decision, July 30—164 tagged, 41 returns (25 per cent)*

Locality of recapture	Number	Days	Locality of recapture	Number	Days
Sumner Strait:			Frederick Sound: Cape Fanshaw	1	2
Cape Decision	2	4–8	Clarence Strait:		
Calder Bay	2	13	Snow Passage	1	6
Rocky Cove	1	11	Point Nesbitt	1	12
Cape Pole	1	7	Blashke Island	1	8
Ruins Point	1	6	Narrow Point	1	11
Point Colpoys	5	4–13	Ernest Sound:		
Totem Bay	1	12	Seward Passage	1	8
Keku Strait	2	6–9	South end of Wrangell Island	1	14
Chatham Strait:			Clarence Strait, south of Ernest Sound:		
Gedney Harbor	1	14	Meyers Chuck	1	8
Port Herbert	1	14	Wolf Creek	1	6
Tebenkof Bay	2	11–13	Turn Point [1]	1	19
North of Washington Bay	3	4	British Columbia: Skeena River	1	21
South of Kingsmill Point	5	4–9			
Red Bluff Bay	1	5			
Basket Bay	1	6			
North of Hawk Inlet	1	8			

[1] Location doubtful.

These results differ materially from those secured from the experiments of 1924 and 1925 at Ruins Point, although this locality is just across Sumner Strait from Cape Decision. In the experiments at Ruins Point a large number of pink salmon went to various localities along the west coast of Prince of Wales Island, and comparatively few went north into Chatham Strait. The conditions were just reversed in this experiment at Cape Decision. None of the pinks tagged there were taken along the west coast of Prince of Wales Island, and a large percentage went north in Chatham Strait. These differences may, of course, be due to chance, but it seems more likely that they are indicative of a distinct difference in the composition of the schools from which the tagged fish were taken. It seems unlikely, however, that such marked differences would be found between the fish at two points so close together at any one time, and we are inclined to ascribe these differences to differences in the runs of 1924 and 1925 as compared with that of 1927. Since the fishery was virtually a failure on the west coast of Prince of Wales Island in 1927, it is not particularly surprising that few fish bound for this region were found among the catches at Cape Decision.

CHUM SALMON

The chums tagged at Cape Decision and again captured followed a northerly route into Chatham Strait without exception. Three individuals were recaptured at Cape Decision 5 to 15 days from the date of tagging. One entered Frederick Sound and was recaptured at Security Bay; four were taken along the Chatham Strait shore of Kuiu Island; and one was recaptured at Point Hepburn on Admiralty Island.

COHO SALMON

Twenty-four coho salmon were tagged at Cape Decision on July 30. Only one was recaptured, and this was taken near Washington Bay, Chatham Strait, in four days.

RETURNS FROM EXPERIMENTS IN CLARENCE STRAIT

RED SALMON

Eleven red salmon were tagged at Gravina Island during 1927, six of which were recaptured (54.5 per cent). Two were taken in Clarence Strait, one in Revillagigedo Channel, and three in Behm Canal. One of those taken in Behm Canal was found at the Yes Bay hatchery of the Bureau of Fisheries during spawning operations.

PINK SALMON

Three hundred and twenty-six pink salmon were tagged at Gravina Island during 1927, 77 of which were recaptured (23.6 per cent). The data are presented in Table 14.

Table 14.—*Returns from pink salmon tagged at Gravina Island, 1927*

Locality of recapture	Locality and date of tagging				Total number recaptured
	Dall Head, Aug. 5		Nelson Cove, Aug. 6		
	Number	Days	Number	Days	
Clarence Strait, north of Dall Head:					
Dall Head			2	1–4	2
Nelson Cove	1	2	5	1–7	6
Gravina Island	3	8–9	1	3	4
East coast, Prince of Wales Island			1	5	1
Guard Islands			3	7	3
Grindall Point			1	8	1
Behm Canal:					
Betton Island			1	4	1
Bond Bay			1	4	1
Smugglers Cove			1	2	1
Helm Bay	1	6	7	2–6	8
Escape Point			1	8	1
Spacious Bay			1	3	1
Bluff Point			1	2	1
Clarence Strait north of Behm Canal:					
Caamano Point	2	3–6	2	3	4
Niblack Point	1	3			1
Ship Island	3	1–4			3
False Island			1	8	1
2 miles north of Ship Island	2	4	2	3	4
Three Islands	1	4	1	3	2
Meyers Chuck			1	4	1
Meyers Island			1	4	1
Lemesurier Point			1	4	1
Clarence Strait north of Behm Canal—Continued.					
Onslow Island			2	4–9	2
Ratz Point			1	11	1
Ernest Sound:					
Union Bay			2	3–8	2
Eaton Point	1	11	6	3–12	7
South end of Wrangell Island			1	7	1
Clarence Strait, south of Dall Head:					
Polk Island			1	8	1
Hotspur Island			1	5	1
Cedar Point	1	5			1
Percy Islands	1	3			1
Duke Island	1	5			1
South Kendrick Bay			1	6	1
Cape Chacon	1	6			1
Nichols Passage: Bostwick Inlet	2	4–10			2
Revillagigedo Channel:					
Slate Islands	1	8	1	7	2
Foggy Bay			1	7	1
Boat Harbor	1	11	1	3	2
Behm Canal, east end: Point Nelson	1	3			1
Total	24		53		77
Percentage returned	27.9		22		23.6

The returns indicate two lines of migration—the main one northerly into Clarence Strait, traversing this body of water to its junction with Behm Canal and also to its junction with Ernest Sound, and a minor one in a southerly direction from the point of tagging. Part of this latter migration crossed Clarence Strait to the Prince of Wales Island shore, where three fish were recaptured. The majority, however, followed the Gravina Island shore and then took an easterly course, scattering to various points

in Felice Strait and Revillagigedo Channel. The time of travel is noticeably short, the minimum being 1 day and the maximum 12 days.

CHUM SALMON

Fifty-two chum salmon were tagged at Gravina Island during 1927. Only three were recaptured (5.7 per cent), one each from the following localities: Seal Cove, Gravina Island, 5 days; Vegas Islands, Felice Strait, 6 days; Clover Passage, Behm Canal, 1 day.

COHO SALMON

Eleven coho salmon were tagged at Gravina Island during 1927. Only one was recaptured, which was taken at Guard Islands, Clarence Strait, in eight days.

CONCLUSIONS

Although the experiments of 1927 involved the tagging of relatively few fish distributed among eight quite distinct localities, the results have corroborated the previous experiments to a remarkable degree. The percentages of recoveries are approximately the same as those obtained in 1924, 1925, and 1926, and are collected in Table 15.

TABLE 15.—*Percentage of tagged fish recaptured, 1927. Total number tagged, 4,668; total number recaptured, 1,506; percentage recaptured, 32.2*

Locality where tagged	Red	Pink	Chum	Coho	King
Icy Strait	27.1	37.7	19.2	18.0	------
Chatham Strait	25.0	32.1	33.5	17.6	15.3
Hourigan Point and Carroll Island	20.0	48.6	26.1	20.6	------
Cape Bendel	10.0	45.2	20.4	14.2	33.3
Point Hobart	17.8	36.5	17.5	------	------
Point Colpoys	30.8	40.2	------	21.4	------
Cape Decision	13.7	25.0	10.9	4.1	------
Gravina Island	54.5	23.6	5.7	9.0	------

The routes of migration are virtually identical with those shown in the earlier work, and in most instances the percentages of fish taking the various routes from a given tagging station are as nearly the same as might be expected. These were discussed in some detail in the report dealing with the experiments in 1926 (Rich and Suomela), and it does not, therefore, seem necessary to repeat that treatment here. The particular value of the experiments described in this report lies in the fact that they support so strongly the previous studies of the migration of salmon in the intricate channels of southeastern Alaska.

UGANIK BAY, 1927

Red salmon are taken in fairly large numbers in the fishery in Uganik Bay on the northern shore of Kodiak Island, particularly in two traps on the western shore. During the season of 1927 126,000 red salmon were reported as captured in this bay, and in 1926 the catch was over 274,000. It was suspected that these might belong to the Karluk River run, and to test this 700 red salmon were tagged and released on August 19 and 20, 1927, from the Broken Point trap of the San Juan Fishing & Packing Co. Three hundred and seventeen tags were taken later in the commercial fishery and were returned with data as to when and where the fish were captured. In addition to those taken in the commercial fishery 86 were observed to reach the Karluk counting weir on their way to the spawning grounds. Some of these were captured, but

the majority continued past the weir and doubtless ultimately reached the lake. The recoveries are shown in Table 16.

TABLE 16.—*Returns from tags attached August 19 and 20, 1927, at San Juan trap No. 1, Broken Point, Uganik Bay, Kodiak Island, Alaska*

Date of recapture	Locality of recapture														Total
	Uganik Bay	South Arm, Uganik Bay	Cape Ugat	Chiefs Point	Spiridon Bay	Uyak Bay	Uyak Bay or Sevenmile Beach	Karluk Beach	Karluk River	Lazy Bay	Viekoda Bay	Raspberry Strait	Cook Inlet	Unknown	
Aug. 19	1		1												2
Aug. 20	5														5
Aug. 21	1			5											6
Aug. 22	7	3				6		58							74
Aug. 23	8				3	3									14
Aug. 24	1	4				10		12			1				28
Aug. 25	5					4						2			11
Aug. 26	8					3		5							16
Aug. 27	4					14		16	6				1		41
Aug. 29								11							11
Aug. 30	5							2							7
Aug. 31					1			11							12
Sept. 1	1	5									2				8
Sept. 2		1						1							2
Sept. 3								2							2
Sept. 4									21						21
Sept. 5						3		3	13						19
Sept. 6								1							1
Sept. 7									21						21
Sept. 8								1	2						3
Sept. 9									1						1
Sept. 10						1		1							2
Sept. 14									2						2
Sept. 15									1						1
Sept. 17									2						2
Sept. 18									11						11
Sept. 19									5						5
Sept. 20									1						1
Doubtful	[1] 8		[2] 7	[3] 2	[4] 5		[3] 47			[5] 3			1	1	74
Total	54	13	8	7	9	44	47	124	86	3	3	2	2	1	403

[1] Reported taken between Aug. 24 and 27.
[2] Reported taken between Aug. 20 and 22.
[3] Reported taken between Aug. 20 and 27.
[4] Reported taken between Aug. 20 and 30.
[5] Reported taken between Aug. 27 and 28.

An examination of this table shows conclusively that the red salmon taken during the latter part of August in the traps along the western shore of Uganik Bay are predominantly derived from the Karluk River run. The 13 that were taken in the southern arm of Uganik Bay were probably, although not certainly, bound for a stream entering the east arm of the bay, which was formerly very productive but is now depleted so seriously that the run amounts to very little. Three were taken in the region of Alitak and presumably represent an element of the Alitak run that passes the northern shore of Kodiak Island during the spawning migration. Seven were taken to the eastward of Uganik Bay, including two taken in Cook Inlet, and one was returned without data as to when and where it had been recaptured. All of the others—399 out of a total of 423 (94.5 per cent)—were taken either at Karluk or at some point between the place where the tagging was done and Karluk, or were reported on their way up Karluk River to the spawning grounds.

The percentage of recoveries was unusally high—57.6 per cent—but this includes 86 fish that were counted through the weir maintained by the Bureau of Fisheries in Karluk River. If we consider only the fish that were taken in the commercial

fisheries, the number of recaptures is 317, or 45.2 per cent. Although this is still a higher percentage of recovery than has usually been reported from similar tagging experiments, it is within the range of the previous results. The recovery of so many tagged fish shows that the fishery is carried on with a considerable intensity in this district, and it can not be doubted that, were it not for the controlled escapement, the catch of Karluk red salmon would be greatly in excess of the 50 per cent required by law.

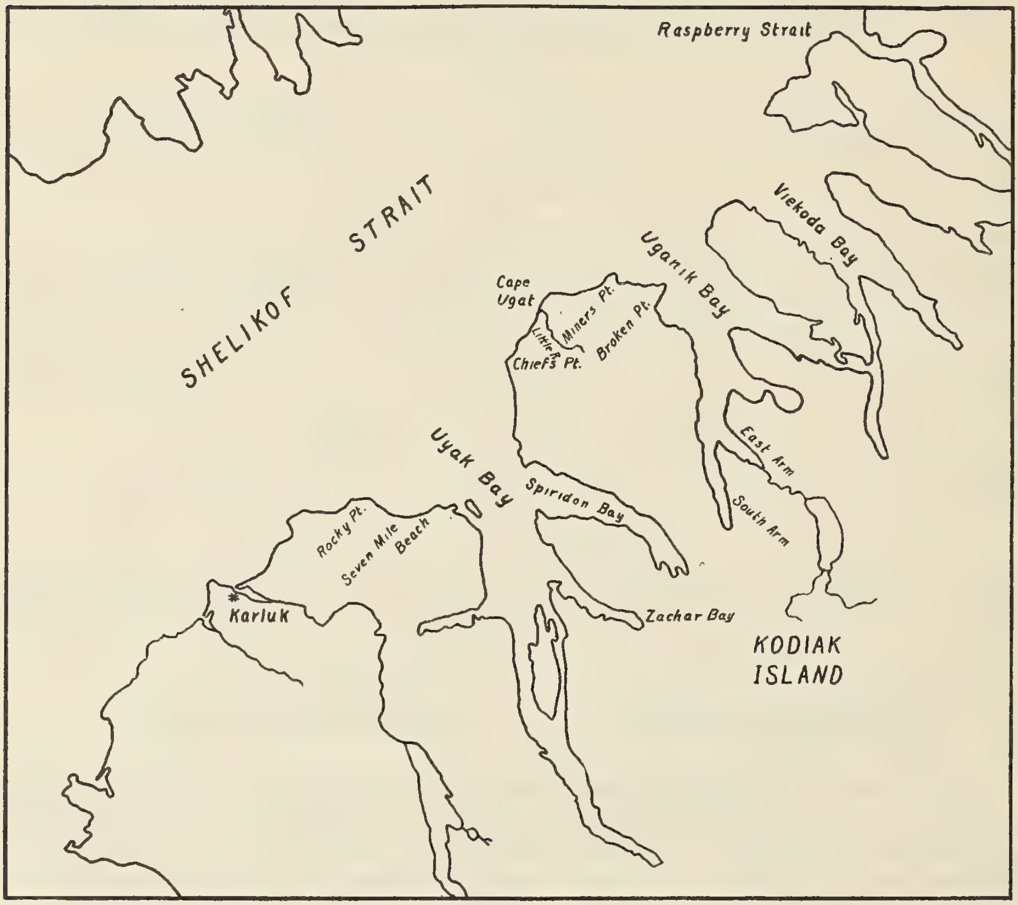

FIGURE 1.—Northwestern part of Kodiak Island, Alaska

It will be noted that over 40 per cent of the tagged salmon were not accounted for, in spite of the facts that the results show that a majority of the fish were bound for the Karluk River, and that the weir in the Karluk River gives opportunity to observe the fish that entered this stream. Without much doubt, this discrepancy is due to the fact that it is impossible to observe carefully all of the fish as they pass through the weir. They are usually moving rapidly and may be as much as 3 feet below the surface of the water. Under such conditions it is inevitable that tagged fish would pass through without being noted, and we believe that this accounts for a large part of the 40 per cent that was unaccounted for.

The rate of travel indicated by the returns is fairly rapid, corresponding, in general, to the rate observed in the experiments on the Alaska Peninsula in 1922 and

1923. Uyak Bay is only some 20 miles from the point of tagging, and Karluk Beach, where most of the tagged fish were recaptured, is about 20 miles farther on to the westward. Fifty-eight tagged fish were taken at Karluk Beach on the 22d, having traveled about 30 miles in 2 or 3 days. The actual rate of travel is more rapid than is indicated by the figures on account of the lapse of time between the actual capture and the finding of the tags. (See Gilbert and Rich.)

It is not known whether these traps in Uganik Bay take Karluk red salmon throughout the season, and it is purposed to secure data that will solve this problem. In the light of our present definite knowledge, however, we must include the Uganik catch of red salmon in the total for the Karluk run, just as is done in the case of the red salmon taken in Uyak Bay.

NICHOLASKI SPIT, 1928

This experiment was designed to test the theory that the red salmon taken at Nicholaski Spit were part of the same run that passes the Shumagin Islands and Morzhovoi and Ikatan Bays, which has been shown by the experiments of 1922 and 1923 to consist largely of Bristol Bay fish. Nicholaski Spit is situated on the western shore of Pavlof Bay, Alaska Peninsula, about halfway between the Shumagin Islands and the end of the peninsula. The fishery here is of recent development, a trap having been driven in 1924 and operated every year since. The late Dr. C. H. Gilbert examined scales of red salmon from this locality and found indications that the catches contained a considerable percentage of Bristol Bay fish. More recent statistical studies also have shown a distinct correlation in the size of the catches at Nicholaski Spit and in Ikatan and Morzhovoi Bays,[3] a fact that lent further probability to this theory.

As originally planned, this experiment was to have been carried out during the height of the red-salmon run in the Ikatan-Shumagin Island district, but additional regulations prevented fishing at Nicholaski Spit until after the 1st of July. Other circumstances made it impossible to tag immediately after the fishing season opened, and it was not until July 11 that the first tags were attached. The main part of the Bristol Bay run has passed through the Ikatan-Shumagin Island district before this time, so that the experiments can not be taken as accurately representing the condition at Nicholaski Spit earlier in the season. In spite of these deficiencies, however, the data show a distinct migration to the westward and into Bering Sea, where tags were taken at Bear River and in Bristol Bay. It seems safe to conclude, in view of all the lines of evidence available, that the fish that pass Nicholaski Spit earlier in the season include Bristol Bay fish, probably in about the same proportion as do the runs in the Shumagin Islands and at Ikatan.

Four hundred and sixty-one tags were attached as follows: 300 on July 11, 74 on July 12, and 87 on July 17. Only 30 tags were recovered (6.5 per cent). This relatively low percentage of recaptures is probably due to the fact that the tagging was done so late in the season. The returns are given in Table 17.

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[3] Statistical Review of the Alaska Salmon Fisheries. Part I: Bristol Bay and the Alaska Peninsula. By Willis H. Rich and Edward M. Ball. Bulletin, U. S. Bureau of Fisheries, Vol. XLIV, 1928, pp. 41–95. Bureau of Fisheries Document No. 1041.

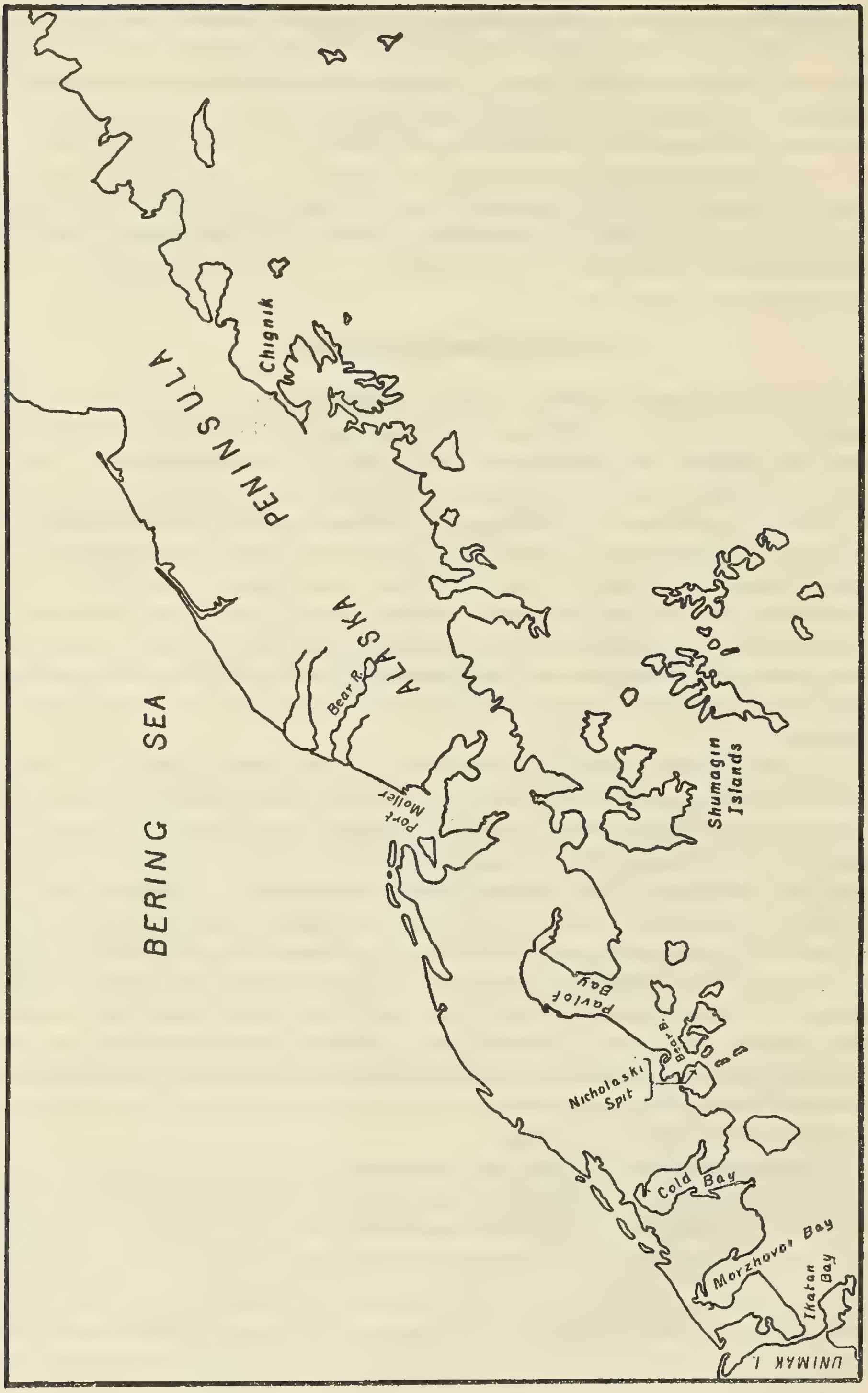

FIGURE 2.—Part of the Alaska Peninsula

TABLE 17.—*Returns from 462 red salmon tagged at Nicholaski Spit, Alaska Peninsula, July 11, 12, and 17, 1928*

Locality of recapture	Date of tagging						Total number recaptured
	July 11		July 12		July 17		
	Number	Days	Number	Days	Number	Days	
Nicholaski Spit	3	0	1	11	2	4–6	6
Long Johns Lagoon, Pavlof Bay	1	12	1	11	2	6–8	4
Bear Bay					1	2	1
Pavlof Bay	1	14			1	6	2
Morzhovoi Bay	2	4					2
Ikatan Bay	3	5	1	4	1	(1)	5
Bear River	1	8					1
Bristol Bay	1	18					1
Chignik	1	17	2	17–26	1	15	4
Little River	1	9					1
Uganik Bay	1	15			1	16	2
Cook Inlet	1	21					1
Total	16		5		9		30
Percentage returned	5.3		6.8		10.3		6.5

[1] Reported taken before date of tagging.

It will be seen at once that the most important migration is to the westward and particularly into the region of Ikatan and Morzhovoi Bays. Approximately one-fourth of the recaptured tags came from these two localities. The movement from Nicholaski Spit to Ikatan and Morzhovoi Bays was very prompt—from four to five days—and in this respect the migration resembles that of the Bristol Bay fish that pass from the Shumagin Islands to Ikatan and Morzhovoi Bays. (See Gilbert, 1923, and Gilbert and Rich, 1925.) These facts lend strong support to the theory that many of the red salmon that pass Nicholaski Spit belong to the same schools that provide the fishery in the Shumagin Islands, and the single return from Bristol Bay is conclusive evidence that at least some of these fish were bound for the streams in that district. It is not surprising that more fish were not taken in Bristol Bay, because the red-salmon fishery there closed on July 23—only 12 days after the first fish were tagged at Nicholaski Spit.

Although the evidence points conclusively to the Bristol Bay origin of a large percentage of the Nicholaski Spit fish, there is also a surprisingly large migration to the eastward, fish being taken at Chignik, Kodiak Island, and Cook Inlet. The earlier experiments in the Alaska Peninsula region had given no indication of any such extensive migration to the east. Most of these earlier experiments were conducted earlier in the season, however, and so were not directly comparable. Some of the later experiments in 1923, however, did show a distinct tendency toward an easterly migration, although by no means as well marked as in the case of the experiments of 1928, in which more than 25 per cent of the returns came from Chignik, Kodiak, and Cook Inlet. There is obviously some indication here that the fishery in the Ikatan-Shumagin Island district does draw to a considerable extent, at least after about the 10th of July, upon the runs originating in streams, such as Chignik, situated to the eastward.

REVIEW OF EXPERIMENTS ON ARTIFICIAL CULTURE OF DIAMOND-BACK TERRAPIN [1]

By SAMUEL F. HILDEBRAND
Director, U. S. Fisheries Biological Station, Beaufort, N. C.

CONTENTS

INTRODUCTION

It is a well-known fact that the diamond-back terrapin (Malaclemmys) once was plentiful. When this animal first came into demand only the terrapins taken in Chesapeake Bay and northward brought a good price, and the more southern terrapins frequently were shipped to dealers at certain points on Chesapeake Bay, to be reshipped from thence to the larger cities as "Chesapeakes." Gradually the Carolina terrapins gained in favor, and more often they were shipped directly to the larger markets. The practice of sending southern terrapins to dealers on Chesapeake Bay, however, appears not to have been discontinued entirely, as the writer has been informed authoritatively that some southern animals are still sent there to be reshipped. It is not known to the writer whether the more northern terrapins actually excel in flavor. It seems probable, though, that the difference is not great or Chesapeake dealers would not, for many years, have been able to sell animals from the South as "Chesapeakes."

[1] Submitted for publication Nov. 16, 1928.

The catch of terrapins, soon after the flesh came into demand, exceeded production, for the animals could not stand a heavy drain, as they do not reproduce rapidly and growth is gained slowly. The natural supply, therefore, was quickly diminished. It was quite evident by the beginning of the present century that these valuable creatures were being reduced so rapidly that very soon they would be so scarce as to make fishing for them unremunerative, if, indeed, the animals were not doomed to extinction. In view of the rapid depletion the Bureau of Fisheries (then the Fish Commission) instituted an investigation in 1902 on Chesapeake Bay, which had for its principal object the determination of the adaptability of the diamond-back terrapin to artificial propagation (Hay, 1905). About the same time the State of North Carolina, in cooperation with the United States Fish Commission at the United States Fisheries Biological Station at Beaufort, N. C., undertook another investigation, which consisted principally of an inquiry into the habits and life history of the terrapin and the condition of the terrapin industry in North Carolina (Coker, 1906). The investigation at Beaufort was discontinued in 1903, but the investigations on the Chesapeake Bay were made more comprehensive. In 1904 a comparatively large wooden pound was built at Lloyds, Md., which provided facilities for holding both young and adult terrapins, and suitable sand beds, in which the terrapins might lay their eggs, were furnished. The experimental work at Lloyds was continued until 1909, when activities were transferred to Beaufort. The series of experiments upon which the present report is based dates from that year.[2]

It was learned from the early experiments conducted at Beaufort, N. C., and at Lloyds, Md., that adult terrapins would produce eggs when confined in pens; also, that the eggs could be transferred from where they were laid to "suitable hatching boxes," where most of them would hatch. Raising the young, however, appears not to have been successful prior to the transfer of the work to Beaufort and the beginning of the present series of experiments in 1909.

A number of attempts to raise terrapins in captivity have been made by private individuals. Most of the private terrapin "farms," however, consist of pens, often called "crawls," in which the animals are placed and fed in order to gain growth or merely to be held for a better market. However, in 1913 a company was organized in Beaufort, which built concrete pounds and a terrapin nursery house and provided itself with all the facilities necessary for raising terrapins. A large brood stock was obtained, and within a few years from 15,000 to 20,000 terrapins per annum were being hatched. This farm progressed nicely until the beginning of the World War and the adoption of the eighteenth amendment to the Constitution. The cost of labor was more than trippled locally, the market value of terrapins dropped, owing to the general curtailment of the use of luxuries during the war, and it seems to have been believed by the manager that under prohibition terrapins never again would be in demand or command the fancy prices paid for them prior to prohibition and the war. In view of these seemingly adverse circumstances, the breeding terrapins as well as some of the young that had attained a marketable size were sold, and in 1918 the plant virtually was abandoned. The Beaufort

[2] Because of the rather frequent changes in the scientific personnel, the experiments were planned by various individuals. The care of the terrapins and the actual work of carrying on the experiments, however, have always been in the hands of Charles Hatsel, the station's able terrapin culturist and foreman. Mr. Hatsel also kept nearly all of the original records, and the success of the undertaking is due, in a very large measure, to his interest and painstaking work.

Terrapin Farm was patterned after the experimental plant of the Bureau of Fisheries, and the success attained in raising terrapins compared very favorably with that of the Bureau of Fisheries.

EXPLANATIONS

Wherever the size of terrapins is mentioned in this paper it refers to the length along the median line of the plastron or lower shell, as this measurement has long been in use in classifying terrapins for the market.

"Carolina terrapins," when used in this paper to designate animals grown in captivity, refer to terrapins that actually are not of "pure blood," because, as shown below, they are the result of a cross between the two closely related subspecies, *Malaclemmys centrata centrata* and *M. centrata concentrata.* This term is used for convenience in distinguishing the Atlantic-coast animals from the Texas-coast species, *M. pileata littoralis*, as well as from certain hybrid lots also used in the experiments.

DISTRIBUTION OF TERRAPINS

Diamond-back terrapins occur on the coasts of the United States from Buzzards Bay, Mass., to Texas. Two species, divided into five subspecies, are recognized by Stejneger and Barbour (1923, pp. 131–132), as follows: The Carolina terrapin (*Malaclemmys centrata centrata*), ranging from central North Carolina to Florida; the Chesapeake terrapin (*M. centrata concentrata*), ranging from Buzzards Bay to North Carolina; the Florida terrapin (*M. pileata macrospilota*), on the Gulf coast of Florida; the Louisiana terrapin (*M. pileata pileata*), ranging from the mouth of the Mississippi River eastward on the Gulf coast to Florida; and the Texas terrapin (*M. pileata littoralis*), which inhabits the coast of Texas and the shores of the outlying islands. The differences between the Chesapeake terrapin and those from the Gulf coast are quite pronounced; that is, the Gulf-coast terrapins have evident tubercles (humps) on the median line of the back, which are obsolete or wanting in the Atlantic species, and generally there are also differences in color that aid in separating the species. The differences between the Atlantic (Chesapeake and Carolina) terrapins, however, are slight. In general, the Carolina terrapin has a larger head, a blunter snout, and the sides (lateral outlines) of the carapace are more nearly parallel and less flaring posteriorly than in the Chesapeake terrapin. These differences usually are evident and are recognized by dealers. However, North Carolina is the geographical meeting place of the Chesapeake and Carolina terrapins. Therefore, it is not surprising that some animals are seen from time to time that are difficult to place in either variety.

The Atlantic varieties (Chesapeake and Carolina) of terrapins have both been used from the very beginning of the experimental work at Beaufort, for the original brood stock (still on hand) was obtained in part from Chesapeake Bay and in part from the general vicinity of Beaufort, where both varieties occur. These terrapins have been confined together in a small pen for almost a score of years, and there is not the slightest doubt that interbreeding is occurring freely. It may be stated here that apparently no inferior stock has resulted from this "crossbreeding," as the offspring raised to maturity in captivity are a fine race of animals and superior in appearance to their parents.

The Chesapeake terrapin is generally preferred on the market, but the difference between it and the Carolina terrapin is so slight that large, fat animals of the last-mentioned variety are accepted readily as "Chesapeakes."

EXPERIMENTS CONDUCTED AND SOURCES OF INFORMATION

At the present time (January 14, 1928) 33 lots of terrapins are on hand at the station. The animals composing the various lots, exclusive of those that comprise the original brood stock, were hatched and grown in captivity and therefore are of known age. Every lot itself forms the basis for a separate experiment or is a part of an experiment. The following are some of the experiments for which the various lots of terrapins are being used: (a) Space requirements for young and adults; (b) size of egg beds required; (c) natural sex ratio; (d) sex ratio required for breeding purposes; (e) practicability for increasing growth, hastening maturity, and reducing the death rate by feeding young terrapins during the winter; (f) the control of disease among recently hatched animals (young terrapins only are mentioned in this connection, as no disease has occurred during the course of the experiments among animals a year or more of age); (g) several experiments in selective breeding; (h) two experiments in crossbreeding the Carolina with the Texas terrapin. Some of the experiments have not been carried on long enough or far enough to yield results, and these will not be reported upon at this time. Others have yielded noteworthy results, however, and the information derived forms the basis for the present report.

The latest previous report [3] made upon this investigation is entitled "Further Notes on the Natural History and Artificial Propagation of the Diamond-Back Terrapin," by R. L. Barney (Bulletin, U. S. Bureau of Fisheries, Vol. XXXVIII, 1921–22 [1922], pp. 91 to 111). Although the present paper essentially is a progress report, nevertheless it is based upon the original data, all of which have been studied carefully. The data presented cover the entire period during which each experiment reported upon has been under way. In the interpretation of the data due consideration, however, was given to the published accounts. A different conclusion occasionally was arrived at, mainly on account of the much more extensive data now at hand and partly because of errors that were corrected and, no doubt, also in part because of a different personal viewpoint.

PRODUCTION OF EGGS

The production of eggs has varied from year to year within broods and even within lots of the same brood, as shown by tables presented herewith. Similar variations have taken place among wild terrapins of unknown age confined for breeding purposes. For example, among a certain lot of wild breeders production has varied from about 7.6 to about 23.9 eggs [4] per female during the period 1915 to 1926, inclusive. It appears to be of interest to mention in this connection that wild terrapins have produced few eggs during the first two and three years of confinement. The

[3] U. S. Bureau of Fisheries Economic Circular No. 60, entitled "Diamond-Back Terrapin Culture at Beaufort, N. C.," by Samuel F. Hildebrand and Charles Hatsel, was issued in October, 1926. This short paper gives only the economic phases of the work and gives no specific account of the many experiments performed nor of the more scientific aspects of the work.

[4] A slightly larger number of eggs per female was produced than shown, as the terrapins themselves accidentally destroyed a few eggs from time to time and rats often destroyed an unknown number. Eggs thus destroyed are not taken into consideration in these data.

records for the original brood stock are rather obscure, but sufficient data are available to show that only a small number of young was produced during the first years of confinement. Similar results (no definite figures are available) were obtained at a local terrapin farm and also for some wild terrapins purchased by the State of North Carolina and confined in 1925 for breeding purposes at the United States fisheries biological (Beaufort) station. The last-mentioned lot, consisting of 478 females and 108 males, laid only 0.8 egg per female in 1925, 1.2 eggs in 1926, and 4.2 in 1927. Another large increase was expected in 1928 but this, for reasons unknown, did not materialize, as the production of eggs remained the same as in 1927.

The largest number of eggs laid per female by any group of terrapins that has been held in confinement during the course of the present experiments was produced by the first brood (1909) hatched and grown in captivity. In the first year few animals were hatched and only four females were grown to maturity. These four animals grew at a fairly uniform rate, and apparently all reached maturity at the same time. The rate of egg production was high and fairly constant, varying during the years 1915 to 1925, inclusive, from 22 to 34.3 eggs per female, with an average for the entire period of 29.4 eggs. The four females in this lot (used in certain dye feeding experiments in 1926, which proved fatal to two of them and sickened the others) appear to have been extremely fertile, and the rate of egg production far surpassed that of the later and larger broods. The broods of 1910 and 1911 probably show to a far greater extent the rate of egg production that may be expected from terrapins grown in captivity. An increase in the average number of eggs laid per female for the lots is expected, as some of them have only recently reached sexual maturity. The tables show that a downward trend in egg production took place from 1919 to 1925 in the two lots of the 1910 brood and also for the winter-fed lot of the 1911 brood. A recovery is indicated for 1926 and a further one apparently will result for 1927, when all the young have been collected and counted. The general downward trend for these broods that took place, therefore, appears to have been only a "fluctuation," which is shown also for the original wild brood stock.

The data appear to indicate that certain years are not as productive of eggs as others. The tables show that egg production in 1921 and again in 1925 was lower than usual for nearly all the lots on hand. The causes for the "lean" years are not obvious. The care and the food received have not varied from year to year. In fact, the animals have remained in the immediate care of the same terrapin culturist throughout the course of the experiments. A study of the weather records kept at the station reveals nothing unusual during the lean years. On the other hand, the winters of 1917–18 and 1918–19 were both unusual, the first one having been extraordinarily cold and the second exceptionally mild, yet each of these winters was followed by a good laying season. The cause or causes of poor laying seasons remains for future investigation.

The great variation in the number of eggs produced by individuals is referred to under the section of this report dealing with fertility, the range given for a single season being from 5 to 29 eggs. Experiments are under way whereby it is hoped to determine whether certain females more or less constantly lay a small number of eggs while others produce a much larger number. These experiments have not been running long enough to yield definite results. The indications are, however,

that among terrapins, as among chickens, certain females are "boarders." If further observations confirm the results already obtained, it should be possible to eliminate the boarders and to select animals of high fertility for breeding purposes.

It appears to be of interest to call attention to the long period of time during which the original brood stock has produced eggs. Some of these animals were confined in 1909 and others in 1912. The early records of egg production by the old breeders are rather obscure, but there is on hand a fairly definite record dating from 1915 to 1926. Table 1 is based upon this record. It is evident from the table that the general trend in egg production over this period of years has been downward. Yet it has fluctuated from year to year, and the rather sharp recovery in 1926 is noteworthy. The age of these animals, as stated elsewhere, is not known, and the length of life of diamond-back terrapins, too, in unknown. Therefore, it is entirely impossible to state that the general decline in egg production is due to old age. Furthermore, the table shows an upward trend since 1921. An upward trend during recent years would scarcely be expected if the general decline were due to old age. For the same reason it does not seem logical to assume that the long confinement affected egg production. Neither can the decline readily be ascribed to food and care, for these have been uniform throughout the period. It seems very difficult, therefore, to find the cause or causes for the decline in egg production from 1915 to 1921, the partial recovery during recent years, and the annual fluctuations that have taken place. The number of eggs destroyed by rats has varied from time to time, but it is not believed that the loss was great enough to affect the results greatly.

TABLE 1.—*Average number of eggs produced by the wild brood stock, based on a lot confined in a single pen from 1915 to 1927*

Year	Eggs	Year	Eggs	Year	Eggs
1915	23.9	1920	13.4	1925	9.8
1916	21.6	1921	7.6	1926	14.8
1917	20.8	1922	8.2	1927	10.1
1918	18.6	1923	9.2		
1919	19.6	1924	11.6	Average	14.5

The yearly egg production by the wild brood stock from 1915 to 1927, inclusive, has averaged 14.4 eggs per female. The average per year for all females 5½ inches [5] and over in length, exclusive of two lots of wild animals recently confined, is 13 eggs per female. This, then, appears to be about the number of eggs per female that may be expected of acclimated animals. It is shown in another section of this report that a rate of fertility of the eggs of about 90 per cent usually prevails when sufficient males are present. These data, then, indicate that in general terrapin-cultural work about 12 young per female per annum may be expected.

[5] The records show that no lot of terrapins grown in captivity has ever produced eggs until at least some of the females had reached a length (on the median line of the plastron) of 5½ inches or more. Therefore, animals less than 5½ inches long are considered immature and are not considered in computing this average.

TABLE 2.—*Average number of eggs produced per female of the brood of 1909* [1]

Year	Eggs [2]	Year	Eggs [2]	Year	Eggs [2]
1915	24.0	1920	35.0	1924	22.0
1916	29.5	1921	32.3	1925 [3]	29.8
1917	24.5	1922	29.4		
1918	29.2	1923	33.0	Average	29.4
1919	34.3				

[1] These animals hibernated each winter.
[2] All of the females in this lot were 5½ inches in length or longer during the entire period.
[3] Discontinued after 1925.

TABLE 3.—*Average number of eggs produced per female of the brood of 1910*

Year	Fed first winter		Hibernated each winter		Year	Fed first winter		Hibernated each winter	
	Entire lot	All 5½ inches and over in length [1]	Entire lot	All 5½ inches and over in length [1]		Entire lot	All 5½ inches and over in length [1]	Entire lot	All 5½ inches and over in length [1]
1915	0.3	1.4	----------	----------	1923	6.1	----------	4.0	----------
1916	5.7	13.4	0.4	4.2	1924	6.0	----------	3.5	----------
1917	8.1	----------	2.9	11.3	1925	5.1	5.9	3.2	4.4
1918	7.6	12.3	4.2	----------	1926	6.5	----------	3.2	----------
1919	11.1	16.2	7.1	13.2	1927	9.2	----------	3.6	----------
1920	9.5	----------	5.1	----------					
1921	6.6	----------	2.1	----------	Average	[2] 6.9	9.8	[2] 3.8	8.3
1922	8.1	----------	5.2	----------					

[1] Female terrapins less than 5½ inches long apparently do not lay eggs. Therefore, the rate of production shown in this column is the actual rate per sexually mature female. Measurements of the size of the terrapins are not available for every year and, therefore, the rate of egg production per mature female can not always be given.
[2] The first year of egg production is not considered in determining this average, as only a few eggs were produced and nearly all of the females were still immature.

TABLE 4.—*Average number of eggs produced per female of the brood of 1911*

Year	Fed first 3 winters		Hibernated each winter		Year	Fed first 3 winters		Hibernated each winter	
	Entire lot	All 5½ inches and over in length [1]	Entire lot	All 5½ inches and over in length [1]		Entire lot	All 5½ inches and over in length [1]	Entire lot	All 5½ inches and over in length [1]
1915	0.1	0.8	----------	----------	1923	7.1	----------	8.7	11.2
1916	0.1	0.3	----------	----------	1924	6.8	----------	8.0	----------
1917	5.3	----------	----------	----------	1925	4.3	5.5	7.5	9.3
1918	7.6	----------	0.7	1.5	1926	8.6	----------	8.6	----------
1919	11.9	18.0	2.3	4.8	1927	7.8	----------	11.6	----------
1920	8.1	----------	5.6	----------					
1921	4.2	----------	6.9	----------	Average	[2] 6.0	6.1	6.7	6.7
1922	6.5	----------	7.1	----------					

[1] Female terrapins less than 5½ inches long apparently do not lay eggs. Therefore, the rate of production shown in this column is the actual rate per sexually mature female. Measurements of the size of the terrapins are not available for every year and, therefore, the rate of egg production per mature female can not always be given.
[2] The first 2 years of egg production are not considered in determining this average, as only a few eggs were produced and nearly all the females were still immature.

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TABLE 5.—*Average number of eggs produced per female of the brood of 1912*

Year	Runts		Selects	
	Entire lot	All 5½ inches and over in length [1]	Entire lot	All 5½ inches and over in length [1]
1919	2.4	5.0	1.6	2.5
1920	4.5	21.1	2.5	31.5
1921	4.1	----------	1.9	----------
1922	6.4	19.5	3.2	41.0
1923	7.6	18.1	2.1	14.2
1924	6.1	----------	3.6	----------
1925	5.1	9.0	1.7	8.9
1926	8.1	----------	3.7	----------
1927	8.5	----------	6.9	----------
Average	5.8	14.6	3.0	19.6

[1] Female terrapins less than 5½ inches long apparently do not lay eggs. Therefore the rate of production shown in this column is the actual rate per sexually mature female. Measurements of the size of the terrapins are not available for every year and, therefore, the rate of egg production per mature female can not always be given.

TABLE 6.—*Average number of eggs produced per female of the brood of 1913* [1]

Year	Entire lot	All 5½ inches and over in length [2]
1920	0.4	----------
1921	.4	----------
1922	1.8	18.2
1923	1.2	8.9
1924	1.4	----------
1925	0.8	4.1
1926	1.5	----------
1927	3.1	----------
Average	1.3	10.4

[1] These animals were fed the first winter.

[2] Female terrapins less than 5½ inches long apparently do not lay eggs. Therefore, the rate of production shown in this column is the actual rate per sexually mature female. Measurements of the size of the terrapins are not available for every year and, therefore, the rate of egg production per mature female can not always be given.

TABLE 7.—*Average number of eggs produced per female of the brood of 1914* [1]

Year	Entire lot	All 5½ inches and over in length
1920	0.4	17.5
1921	.3	----------
1922	.8	6.8
1923	1.4	12.1
1924	1.6	----------
1925	0.7	6.8
1926	1.7	----------
1927	4.5	----------
Average	1.4	10.8

[1] These animals were fed the first winter.

FERTILITY OF EGGS

The percentage of fertility of the eggs has fluctuated greatly from year to year and often within a single small lot. For example, in a lot of terrapins hatched in 1910 (fed the first winter), which consists of 13 males and 116 females, the percentage of fertile eggs has varied from 79.2 to 92.8 the average for the period 1915 (when the terrapins laid for the first time) to 1926, inclusive, being 85.2 per cent. In another lot hatched in the same year (1910), but which was allowed to hibernate each winter, now (1928) consisting of 5 males and 87 females, fertility has ranged from 57 to 91.9 per cent, with an average for the period 1917 [6] to 1926, inclusive, of 71.8 per cent.

[6] This lot laid for the first time in 1916, but the number of eggs produced was so small that the results for that year do not appear to be worthy of consideration.

Tables 8 to 15 show in detail the approximate number of eggs produced each year, the number of young hatched, and the percentage of fertility. It is difficult to account for the wide yearly fluctuations in the fertility of the eggs that have occurred in nearly all lots on hand. In general, the highest percentage of fertile eggs has been produced by those lots having the largest proportionate number of males. Examples of a high degree of fertility, as already shown, occurred in the wild brood stock (Table 8), in which the ratio of males to females has usually been about 1 to 2. A very high percentage of fertile eggs was laid from 1918 to 1925 by a small brood hatched in 1909, in which there also was one male to two females. During the first three years in which eggs were laid by this brood the percentage of fertile ones ran very low, and then, as shown by the table, fertility suddenly increased and thereafter remained fair to very high.

The lowest percentage of fertility among the older broods, for which considerable data are at hand, occurred in a lot belonging to the brood of 1911 (Table 11), which was allowed to hibernate each winter. This lot now (1928) consists of 3 males and 35 females. Egg laying began in 1918. Since no males were penned with the females until the fall of 1919, the eggs for the first two summers were not fertile and have not been considered in these data. Fertility has varied from 23.6 to 89.7 per cent during the period 1920 to 1926, inclusive, with an average fertility for the whole period of 64.8 per cent. Another lot of the same brood (1911), consisting of 38 females (originally penned with the lot just discussed) and 3 old males taken from the original brood stock, has produced consistently a higher percentage of fertile eggs over the same period of years. Fertility in this lot was the lowest in 1921, when only 71.4 per cent of the eggs hatched, and it was highest in 1925, when 93.4 per cent of the eggs were fertile, the average fertility for the entire period being 81.5 per cent. It seems probable, although by no means certain, that the higher fertility in the last-mentioned lot may have been due to the old and fully matured males that were introduced, whereas it is not known that the young males of the other lot were all mature when eggs first were produced.

It is a well-known fact that all females of one age do not become mature at the same time. Some females, in fact, require several years longer to reach sexual maturity than others. The same very probably is true of the males. This subject is discussed more fully in another section of this paper (see p. 56). The fact that the percentage of fertility in the lot penned with young males increased each year (Table 11) until 1925 lends support to the belief that the number of mature males present may have been insufficient. It will be seen, also, from Table 11 that the lot penned with young males each year produced a larger number of eggs than the other one, notwithstanding that there were three more females in the pen with the old males. This suggests earlier maturity for a larger proportion of the females penned with young males than for those penned with old males, and this, too, may have had a bearing upon fertility in relation to the number of males present.

Owing to such great fluctuations in egg production, it can not be stated definitely that one of the two lots of the brood of 1911, compared in the preceding paragraphs, produced a greater number of eggs than the other because it contained a larger number of mature females, for the difference in egg production, as just shown, may have

been due to a difference in fecundity rather than to the number of mature females present.

The highest degree of fertility for all broods on hand or used at one time or another in the many experiments conducted has almost consistently occurred among wild terrapins (Table 8) that have been confined for breeding purposes. The product of all wild animals is considered together here for convenience, although these terrapins have been separated into smaller lots at various times. To give a record of each lot separately would require much space. When last enumerated (1926) there were on hand 39 males and 72 females belonging to this "wild stock," and this ratio has not varied greatly for several years. Fertility among the wild terrapins, or the "orignal brood stock," during the period 1912 to 1926 was lowest in 1912, which was the first year of confinement for the majority of these animals, when 83.9 per cent of the eggs hatched. Two years later (1914) it was the highest that it has ever been, namely, 97.9 per cent. The average fertility for the entire period was 94.4 per cent.

In the case of a few groups of animals the results with respect to fertility, as related to sex ratio, are contrary to the more general rule stated in a preceding paragraph, namely, that a large proportionate number of males tends to bring about a high percentage of fertile eggs. The 1910 brood (Table 10), for example, was divided into two lots. One lot was fed the first winter, the other being allowed to hibernate. The first-mentioned lot has one male to nine females and an average percentage of fertility for the entire period during which eggs have been produced (1915 to 1926) of 85.2 per cent; whereas in the hibernating lot, in which there is a ratio of one male to 7.8 females, the percentage of fertility during the period (1916 to 1926) in which eggs have been produced is only 71.8 per cent.

It is evident from the foregoing discussion that the reason or reasons for the great fluctuations in fertility among the various lots and broods and even within a single lot and brood are not understood, and that sufficient data are not yet at hand from which specific recommendations relative to the proper sex ratio that should be maintained for breeding purposes may be made. This question is further complicated by the fact that females appear to produce a high percentage of fertile eggs for at least two years without recopulation. Thereafter, fertility apparently drops rapidly. This conclusion is based upon the results obtained from penning 10 old females without males. During the first season following separation from males these 10 females laid 124 eggs, and only 1 failed to hatch; during the second summer 116 eggs were produced and 14 failed to hatch; during the third summer 130 eggs were laid and 91 failed to hatch; and during the fourth summer 108 eggs were produced and only 4 hatched. Thereupon, seven old males were introduced, and in the next season 145 eggs were laid, of which only 4 failed to hatch. The results of this experiment would indicate that annual copulations are not necessary, and that very few males would suffice for breeding purposes. The combined records for all adult terrapins on hand appear to show, however, that the highest rate of fertility is obtained when the males are fairly numerous. The indications are that for breeding purposes a ratio of about 1 male to 5 females should be maintained.

TABLE 8.—*Production and fertility of eggs of the original wild brood stock, most of which were confined between 1909 and 1912. Males, 39; females, 72* [1]

Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile
1912	1,337	1,121	83.9	1918	1,157	1,113	96.2	1924	870	829	95.3
1913	1,374	1,289	93.9	1919	1,451	1,398	96.4	1925	719	680	94.6
1914	1,411	1,381	97.9	1920	939	915	97.5	1926	1,065	985	92.5
1915	1,480	1,415	95.7	1921	531	512	96.5	1927	733	626	92.2
1916	1,415	1,335	94.4	1922	615	566	92.1				
1917	1,275	1,215	95.3	1923	686	654	95.4	Total	17,058	16,084	94.2

[1] The number of females in this brood stock was reduced from 123 in 1912 to 72 in 1927, which accounts in part for the smaller number of eggs produced during recent years.

TABLE 9.—*Production and fertility of eggs of the 1909 brood, which hibernated. Males, 2; females, 4*

Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile
1915	96	17	17.5	1920	140	126	90.0	1925 [1]	119	116	97.5
1916	118	75	63.5	1921	129	120	93.1				
1917	98	72	73.5	1922	118	114	96.6	Total	1,293	1,098	85.0
1918	117	112	95.8	1923	132	129	97.7				
1919	137	129	94.2	1924	89	88	98.9				

[1] Discontinued after 1925.

TABLE 10.—*Production and fertility of eggs of the 1910 brood*

Year	Fed first and in part in the second winter. Males, 13; females, 116			Hibernating each winter. Males, 5; females, 87			Year	Fed first and in part in the second winter. Males, 13; females, 116			Hibernating each winter. Males, 5; females, 87		
	Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile		Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile
1915	39	34	87.2	------	------	------	1923	710	648	91.3	360	233	64.7
1916	754	587	77.9	38	37	97.3	1924	697	606	87.0	304	218	71.8
1917	1,071	902	84.3	260	214	82.3	1925	592	549	92.8	283	223	78.8
1918	1,015	934	92.2	379	348	91.9	1926	757	652	86.2	281	203	72.3
1919	1,428	1,136	79.5	633	475	75.1	1927	1,071	768	71.7	318	221	69.5
1920	1,111	932	83.9	456	263	57.7							
1921	768	687	89.5	187	128	68.5	Total	10,950	9,228	84.2	3,961	2,836	71.6
1922	937	793	84.7	462	273	59.1							

TABLE 11.—*Production and fertility of eggs of the 1911 brood*

Year	Fed first 3 winters. Males, 10 "old"; females, 78 [1]			Hibernated each winter (2 lots)					
				Males, 3; females, 35			Males, 3 "old"; females, 38 [2]		
	Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile
1917 [3]	445	417	93.3	------	------	------	------	------	------
1918	628	582	92.7	------	------	------	------	------	------
1919	973	821	84.4	------	------	------	------	------	------
1920	641	572	89.3	[4] 250	59	23.6	187	152	89.1
1921	336	302	89.9	394	182	46.2	160	114	71.4
1922	515	461	89.6	387	228	59.0	170	127	74.2
1923	561	529	94.3	452	305	67.5	224	174	77.7
1924	529	471	89.1	353	252	71.4	253	215	85.2
1925	335	311	92.9	367	329	89.7	181	169	93.4
1926	673	532	79.1	336	290	86.3	294	245	89.4
1927	613	463	75.5	454	288	61.2	393	320	81.4
Total	6,249	5,461	87.3	2,993	1,933	64.5	1,862	1,516	81.4

[1] This lot of terrapins upon maturity proved to be all females. 10 old males taken from the original brood stock of wild terrapins of unknown age were then added.
[2] Three old males taken from the original brood stock were added in 1919.
[3] In 1915 and 1916 a few eggs were produced but they are not considered in calculating fertility, as the number is too small to be of significance.
[4] Eggs were produced for 2 years prior to this date but are not considered in calculating fertility as the females were penned without males.

Table 12.—*Production and fertility of eggs of the 1912 brood*

Year	Smallest (runts) of the entire brood selected at 1 year of age, in part fed the first winter and all the second winter. Males, 10; females, 54			Largest selected from entire brood at 1 year of age, all fed first 2 winters. Males, 17; females, 67			Year	Smallest (runts) of the entire brood selected at 1 year of age, in part fed the first winter and all the second winter. Males, 10; females, 54			Largest selected from entire brood at 1 year of age, all fed first two winters. Males, 17; females, 67		
	Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile		Eggs laid	Young hatched	Per cent fertile	Eggs laid	Young hatched	Per cent fertile
1919	135	102	75.5	124	113	91.2	1925	279	247	88.5	116	116	100.0
1920	255	226	88.7	189	161	85.2	1926	447	395	88.4	255	209	82.0
1921	228	182	79.9	142	130	91.6	1927	461	396	85.9	459	392	85.3
1922	350	288	82.5	246	227	92.3							
1923	416	356	85.6	171	167	97.7	Total	2,907	2,480	85.3	1,953	1,750	89.6
1924	336	288	85.8	251	235	93.7							

Table 13.—*Production and fertility of eggs of the 1913 brood, which were fed first winter. Males, 4; females, 75*

Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile
1920	31	29	93.1	1925	61	41	67.0
1921	42	35	83.3	1926	115	60	49.0
1922	146	73	50.4	1927	234	157	67.0
1923	101	88	87.1				
1924	118	101	83.2	Total	848	584	69.1

Table 14.—*Production and fertility of eggs of the 1914 brood, which were fed first winter. Males, 2; females, 83*

Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile
1920	35	35	100.0	1925	61	61	100.0
1921	26	12	46.2	1926	140	99	71.0
1922	75	34	46.4	1927	371	241	64.9
1923	121	121	100.0				
1924	147	147	100.0	Total	976	750	76.8

Table 15.—*Production and fertility of eggs of the 1916 brood, which were fed first winter. Males, 40; females, 158*

Year	Eggs laid	Young hatched	Per cent fertile	Year	Eggs laid	Young hatched	Per cent fertile
1922	2	2	100.0	1926	133	122	91.8
1923	34	34	100.0	1927	219	183	83.6
1924	63	61	96.9				
1925	52	44	84.6	Total	503	446	88.6

RECORDS OF SURVIVAL

During the entire course of the experiments no evident diseases have occurred among the terrapins after they had attained an age of about 1 or 2 years, and thereafter the loss from this source has been negligible. A very considerable death rate, apparently due to disease, has occurred among the young. Further remarks con-

cerning diseases are to be found in subsequent paragraphs. A definite record of the deaths that have occurred can not be given because several animals in nearly every lot are *missing.* Some of these animals may have died unnoticed (especially when they were small), others undoubtedly were carried away by rats, birds, or other enemies, or, again, they may have found an avenue for escape. It is definitely known that in a few instances a number of animals got away during storms, when the water nearly reached the top of the walls of the pens. On the other hand, not infrequently the missing animals simply were overlooked when a census was taken. It is very difficult, because of their very proficient hiding propensities, to find all the terrapins in an inclosure even though the pen be small. Therefore, the "missing" animals of one census sometimes reappeared in the next one. On account of the impracticability of getting and keeping definite records of deaths and escapes only the animals found when a census was taken were considered in many of the tables appearing in this report. From a practical standpoint, the animals that are missing, of course, are of no more significance (unless they can be found) than the dead ones, and the proportionate number of those hatched that may be grown to maturity is of chief importance.

Many of the terrapins grown in captivity, as stated elsewhere, were selected, and the entire brood was kept only in 1910,[7] when only a small number was hatched. This brood originally consisted of 293 animals. It was divided into two lots. One lot, consisting of 120 individuals, was allowed to hibernate, and the other one, consisting of 173 animals, was kept warm and fed the first winter and part of the second winter. At the age of 1 year 93 per cent of the winter-fed terrapins and 85.8 per cent of the hibernating ones were alive. At 6 years of age, when at least some of the animals had become sexually mature and reproduction had begun, 83.2 per cent of the winter-fed lot and 78.3 per cent of the hibernating one still survived, and at 15 years of age 74 per cent of the former and 76.6 per cent of the latter lot were found.

In two unselected lots of the brood of 1911, each originally consisting of 100 terrapins, the percentage of survival at 1 year of age was 95 for the winter-fed lot and 89 for the hibernating one. At 6 years of age 82 per cent of the winter-fed animals were found and 78 per cent of the hibernating ones, and at 15 years 77 per cent of the former and 76 per cent of the latter were on hand.

The four lots discussed in the preceding paragraphs are the only ones of those at hand that have reached maturity that were carried through as separate lots and without selection from the time of hatching to maturity. All the other lots of mature terrapins were selected at about 1 or 2 years of age from lots that had been fed the first winter, and therefore the records are not continuous and not directly comparable with those of the 1910 and 1911 broods.

Winter feeding in an especially constructed brooder house[8] was begun with the 1913 brood. The object of winter feeding, of course, was mainly to increase the growth of the young animals. The results of this project, with respect to the rate of growth, are discussed in another section of this paper. Its results with respect to mortality or survival, however, appear to belong to the present section of this report.

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[7] In 1909 only a few terrapins were hatched, of which only 12 grew to maturity. This number is regarded as too small to be of much significance and is omitted in this discussion.

[8] A description and photograph of the terrapin brooder house used in these experiments may be found in Bureau of Fisheries Economic Circular No. 60, 1920, pp. 17 and 18, fig. 8.

Winter feeding, from the standpoint of survival, has resulted in varying degrees of success. The highest percentage of survival during the course of the experiments was obtained in the 1915 brood when 97.6 per cent of 1,306 animals placed in the brooder house in October, 1915, lived until May 15, 1916, at which time the surviving ones were removed from the house and placed in outdoor pens (Table 17). The results for the preceding brood (1914), however, were the most unsatisfactory, from the standpoint of survival, obtained to the present time (1928). Of 1,349 animals placed in the brooder house only 53.9 per cent lived until May 24, 1915, when the surviving ones were removed from the house.

The best results under more crowded conditions, such as have prevailed during recent years in the nursery house, were obtained with the brood of 1921, of which 2,395 young were placed in the house in October, 1921. Of this number 87.7 per cent lived until May, 1922, when the surviving ones were removed from the house (Table 17), and this rate, under similar conditions, has not fallen below 68.6 per cent to the present time (July, 1928).

Various methods of sanitation, several different kinds of food, fresh and salt water, and wooden and metal (galvanized-iron) tanks have been employed, but generally with indifferent success with respect to mortality. After an epidemic of a disease (elsewhere described and designated as "sores") in the brood of 1914, the tanks were disinfected weekly with a solution containing potassium permangenate and sodium bicarbonate. In 1922 this method of disinfecting the tanks was abandoned largely because it did not prevent the growth of algæ. Food and excreta readily became lodged in the algæ, fouling the tanks, and it was necessary to scrape the tanks to keep them clean. Thereafter an extra tank was provided, making it possible always to have an empty one, and the animals were shifted at about weekly intervals. Each trough was allowed to dry, and before replacing the animals it was scalded with hot water. This treatment prevented the growth of algæ, and a considerable amount of work previously necessary to keep the tanks clean was saved. The results with respect to mortality, however, were quite indifferent (Table 16).

It would appear from the rather unsatisfactory records that the death rate during the first winter among young terrapins subsisting on foods producing the greatest gain in growth (oysters and fresh fish) increased, whereas it decreased when food (salted fish) producing little growth was supplied. It does not necessarily follow, however, that a larger percentage of the slow-growing animals would reach maturity, for the larger and more robust ones appear to stand a much better chance of survival when liberated or placed in outside pens. Unfortunately, the data bearing upon this phase of the work are very meager. Animals kept in salt water had the appearance of being healthier, and generally the death rate appears to have been a little lower. It has been thought necessary, however, to supply such animals with fresh water once a day, which increases the amount of labor, and the slight advantage gained may not be sufficient, in practical terrapin culture, to offset the extra amount of work involved. A few galvanized-iron tanks have been in use for several years. Such tanks are kept clean somewhat more easily than wooden ones, but no advantage from the stand point of mortality is apparent.

Different degrees of crowding of the animals have been tried in the brooder house with the view of determining the space requirements of the young animals. In this

series of experiments tanks 8 feet long and 20 inches wide, divided into four equal compartments, have been used. Each compartment, therefore, had a floor space of about 20 by 24 inches. In some of the compartments 25 to 50 animals were held, 100 in others, and in still others 125 to 150 were placed. The experiment was carried through three seasons (October to May, 1923 to 1926) using each year an equal number of compartments for the different degrees of crowding. The rate of survival is very slightly in favor of the least crowding, for of 325 animals used, 80 per cent survived. Of 1,100 terrapins held 100 to a compartment, 79.5 per cent survived, whereas under the crowded condition of 125 to 150 animals to a compartment only 70.7 per cent of a total of 1,530 terrapins survived. The results with respect to the rate of growth for the different degrees of crowding are discussed elsewhere. It is sufficient to state here that they bear a relationship to each other somewhat similar to the rate of survival. It may be concluded, therefore, that it is practicable to confine as many as 100 young terrapins in a space having an area of 20 by 24 inches.

The death rate among the young animals that are allowed to hibernate frequently is almost negligible during their first winter, as in the brood of 1926, of which 99.9 per cent of 1,627 animals survived (Table 17). However, in a few instances the death rate has run very high, as, for example, in the brood of 1922, in which only 44.7 per cent of 789 animals survived the winter.

Records of survival of the hibernating animals, as well as the winter-fed ones, as far as data are available, are given in Table 17. The percentage of survival of the winter-fed and hibernating terrapins, given in the table are not directly comparable, as the hibernating ones usually emerged from hibernation and were counted during the latter part of March or early in April, whereas the winter-fed animals each year were counted from four to six weeks later; that is, at the time they were removed from the nursery house. During the first four to six weeks after emerging from hibernation the death rate usually is quite heavy and generally much greater than in non-hibernating animals. Therefore, Table 17 does not contain directly comparable data, with respect to survival, of the advantages of one method over another. It does show, however, the yearly fluctuations in the rate of survival during the early months of life that has taken place during the course of the experiments, both for hibernating and winter-fed animals.

The fluctuations in the death rate in the winter-fed animals can be accounted for, in part, by the prevalence of a cancerous disease (elsewhere referred to as "sores") that as yet (1928) is of unknown origin and for which no preventive or cure has been found. This disease, which outwardly makes its appearance as sores chiefly on the tail or as discolored areas on the plastron, has always existed among winter-fed animals throughout the course of the experiments. However, it reached serious epidemic proportions only in the 1914 and 1927 broods, when the rate of survival, as shown in Table 17, was greatly reduced. Deaths have occurred from other causes, of course; principally of "soft shell" and a few of "limber neck" and miscellaneous causes. The deaths from these sources, too, have varied and are the cause of a part of the great fluctuations.

The disease designated as "soft shell" is associated with a failure to eat, resulting, of course, in a failure to grow and in general emaciation. The majority of cases of soft shell occur among young that never have been induced to take food, although rather

rarely it occurs in animals that have fed and have gained some growth. Animals that fail to take food are inactive, and they seldom enter the water but seek the sun and heat. Many of these animals die, but others often suddenly begin to feed, and a rather rapid recovery (for a terrapin) takes place. For example, 200 soft-shell terrapins (the very poorest) were selected late in May, 1927, from 2,180 winter-fed terrapins of the 1926 brood. Of the 200 animals selected, 74 were living on August 15, 1927, when they were liberated. All had gained some growth, the shells had become hard, and, with the exception of 1 animal that had a tail lesion, all gave the appearance of being healthy and sound.

Soft shell, except possibly during 1914, when a severe epidemic of sores existed, has caused the greatest loss among winter-fed terrapins. The loss from this source, combined with minor losses from limber neck, etc., for the several broods (1920 to 1927) for which fairly accurate data are available has ranged from 10.3 per cent (1921 brood) to 23 per cent (1924 brood). Table 16 shows in detail the percentage of deaths among winter-fed animals ascribed principally to soft shell and those due to sores. Soft shell, too, appears to be the chief cause, during their first summer, of the heavy mortality among terrapins that hibernated.

Limber neck apparently is a form of paralysis, which most frequently causes the animal to lose the use of the muscles in the neck and fore limbs, but occasionally it affects only the hind limbs or the control of all muscles may be lost. Few recoveries have been noticed. No definite records of the death rate caused by this disease are available, but it quite certainly has never exceeded one-half of 1 per cent and, therefore, is quite negligible.

The cause or causes of the great fluctuations in the death rate of hibernating terrapins is much more difficult to find. Since the animals do not feed during the hibernation period, nor have fed previously, and since they do not expose themselves to light but lie buried underneath sand, sod, or débris, food and light appear to be eliminated as factors influencing survival. Weather conditions—that is, temperature and precipitation—appear to be the most plausible influences to consider. Precipitation is of little importance, however, as the hibernating animals are provided with covered quarters,[9] into which little rain can enter, and moisture is provided artificially. Therefore, rainfall appears to be of little importance. A careful study of temperature records has revealed nothing. The greatest mortality that has occurred during the course of the experiments, as shown by Table 17, took place in the brood of 1922. In the 1926 brood it was negligible.

In view of the contrast in the death rate of young hibernating terrapins, temperature records (kept at this station in cooperation with the United States Weather Bureau) were carefully compared for the months during which the 1922 and the 1926 broods were in hibernation. Comparing temperatures, month by month, for the two seasons, the greatest difference occurs in February, for the average maximum and minimum temperatures each were 9.5° F. higher in 1927 than in 1923. The highest temperature on any one day during February, 1927, was 74° and the lowest

[9] A description of the winter quarters provided for hibernating terrapins is given in Bureau of Fisheries Economic Circular No. 60, 1926, p. 16.

was 28°. The highest temperature reached in 1923 was 66° and the lowest was 23°. None of these temperatures is regarded as unusual. The differences in the averages for the other months do not exceed 4°; nor are any of the daily temperatures regarded as excessively high or low. Certainly, if low temperatures were a detriment, the brood of 1917 would have perished, as the winter of 1917–18 was by far the coldest that has occurred during the course of the experiments (definite temperature records for this winter, unfortunately, are not at hand). The mortality records show, however, that only 1 of 735 animals placed in hibernating boxes died that winter. The highest percentage of survival throughout the course of the experiments, then, appears to have occurred during an excessively cold winter and again (1926) during a moderate winter. Therefore, it is not evident that the fluctuations in winter temperatures as they have occurred at Beaufort in the years during which the present experiments have been under way have affected the death rate of young hibernating terrapins.

The hibernating terrapins have been kept in winter quarters that have varied little, and the care has been about the same and in the hands of the same terrapin culturist from the beginning. It is evident, therefore, that the cause or causes for the pronounced differences in the death rate of various broods of young hibernating terrapins has not been found, and this subject remains for future investigation.

Table 17 shows that in 9 of a total of 14 broods the percentage of terrapins that lived until they were removed from their winter quarters was greater among the hibernating terrapins than among winter-fed ones. However, the hibernating ones, as already stated, each year were taken from their winter quarters and counted four to six weeks earlier than the winter-fed lots. It has been pointed out elsewhere that the death rate usually has been quite heavy during the first several weeks after the terrapins emerge from hibernation and certainly much heaveir than in the winter-fed animals for the same period of time. Definite statistics are not available for comparison, but our terrapin culturist and the writer have not the slightest doubt, from their observations extending over several years, that by the middle of May, when the winter-fed terrapins usually were counted, the percentage of survival among them at that time, for all years combined, exceeded that of the hibernating animals. Furthermore, the winter-fed animals nearly all had gained some growth and thereafter had a much better chance to survive. A few comparatively large lots of terrapins have been retained at the laboratory during recent years, and although the records are marred by depredations wrought by rats, a far larger percentage of the winter-fed lots than of the hibernating ones survived to reach an age of 1 and 2 years, and the deaths from natural causes certainly were much greater among the hibernating animals than among the winter-fed ones.

The early broods (1910 and 1911) carried to maturity in captivity, as indicated in a preceding paragraph, appear to show that winter feeding, from the standpoint of survival, has a slight advantage. Later records (if they were not clouded with missing animals killed and frequently carried away by rats), it is confidently believed, would show a much greater advantage in winter feeding than the early ones. Our terrapin culturist and the writer are both firmly convinced (although they are unable to supply

definite statistics) that a much larger percentage of winter-fed than of the hibernating terrapins (if both were retained in equal numbers) would survive to reach an age of 2 or 3 years. Thereafter, as shown elsewhere (Table 19), the death rate is small. Winter feeding, even though considered only from the standpoint of survival and entirely aside from the faster growth and earlier maturity, undoubtedly is advantageous.

The percentages of survival of most of the lots of terrapins that were hatched and raised, or partly raised, in captivity are shown in Table 18. In this table "missing" terrapins are counted as dead, and the percentages are based upon the surviving ones only. In next to the last column is given (except in those lots in which the terrapin were carried through from hatching to maturity without selection and without removing any of the original number) the percentage of the whole lot that probably would have survived had they been retained. In making the calculations it is assumed that equally as large a percentage of the entire broods or lots from which selections were made would have survived, had they been kept in captivity, as of the smaller lots selected. This appears to place the probable averages of survival a little too high, because in most instances the largest and finest animals were retained. The probable percentage of survival at 6 years of age (when at least some of the animals had reached sexual maturity) for all lots combined is 60.7. If depredations by rats could have been avoided, the average percentage of survival undoubtedly would have been considerably greater. It is quite certain, also, that in a plant built in the light of the knowledge gained from the experiments conducted and constructed especially for terrapin growing a somewhat better average could be attained. On the other hand, the average of 60.7 per cent of survival apparently compares favorably with results obtained in chicken farming. (See Hildebrand and Hatsel, 1926, p. 15, footnote.)

It was stated in the first paragraph of this section that accurate records of deaths are not available. However, after a terrapin has reached an age of 3 years or more it is of a sufficiently large size that a dead one in a pen scarcely would be unnoticed. Table 19, giving the number of terrapins at 3 years of age in various lots held in confinement, together with the deaths that were noticed during their third year and thereafter until disposed of or last counted, nevertheless appears to be of interest. It is evident at once that the death rate has been consistently low. Generally it was impossible to determine the cause or causes of the deaths that have occurred among the larger terrapins.

The low death rate (see Table 19) that has occurred among the wild brood stock is noteworthy. Some of these animals were confined in 1909, others in 1911, and a few appear to have been held over from certain experiments conducted in 1902. Most of these animals were mature when confined, but not all of them, as stated by Barney (1922, p. 94) and Hildebrand and Hatsel (1926, p. 13). Measurements of the first lot of breeders, taken when purchased in Beaufort in 1909, have been found recently among the early records, and these show that 10 of 45 females obtained in this lot were less than 5½ inches long and therefore almost certainly sexually immature. The second lot of breeders, bought in 1910 and 1911, also appears to have contained at least 6 of a total of 43 females that were less than 5½ inches long. It seems to be incorrect, therefore, to say that all the wild terrapins were mature when

confined. On the other hand, some of them probably already were very old. The shells of some of these old animals have been worn smooth, leaving no trace of growth rings, which are prominent in younger terrapins. The writer does not care to venture to make an analysis of the age [10] of these terrapins. A conservative estimate, in the opinion of our terrapin culturist and the writer, is that the ages range from 25 to possibly 40 years or more. It is pointed out in the section of this report dealing with egg production that there is as yet no conclusive evidence indicating that these animals are declining in egg production because of old age; nor is the death rate such (only two deaths having occurred during the past four years) as to suggest old age. The span of life of a diamond-back terrapin, therefore, remains undetermined.

TABLE 16.—*Percentage of deaths caused by sores and other causes among winter-fed terrapins*

Brood	Animals fed	Per cent of deaths due to sores	Per cent of deaths due to other causes, principally soft shell	Brood	Animals fed	Per cent of deaths due to sores	Per cent of deaths due to other causes, principally soft shell
1920	2, 502	[1] 4. 9	14. 7	1924	2, 407	6. 3	23. 0
1921	2, 395	3. 7	10. 3	1925	2, 391	2. 0	13. 2
1922	2, 787	3. 7	21. 4	1926	2, 936	2. 4	20, 8
1923	2, 427	2. 3	12. 7	1927	3, 720	13. 4	15. 0

[1] The combined percentages of deaths due to sores and all other causes do not quite equal the percentages of loss shown in Table 17, because each year a small number of animals is missing and in the table showing survival such animals are counted as dead.

TABLE 17.—*Survival of young terrapin during their first winter* [a]

Year	Terrapins fed in nursery house	Per cent survived	Animals hibernated	Per cent survived	Year	Terrapins fed in nursery house	Per cent survived	Animals hibernated	Per cent survived	Year	Terrapins fed in nursery house	Per cent survived	Animals hibernated	Per cent survived
1912 [b]	500	92. 6	480	95. 0	1917	1, 481	82. 5	735	99. 9	1923	2, 427	85. 0	993	93. 8
1913	525	96. 0	716	99. 7	1919	2, 937	82. 0	1, 590	70. 6	1924	2, 407	68. 6	1, 163	99. 0
1914	1, 349	53. 9	254	82. 2	1920	2, 502	79. 6	1, 404	99. 5	1925	2, 391	85. 0	1, 066	81. 3
1915	1, 306	97. 6	736	87. 2	1921	2, 395	87. 7	231	82. 2	1926	2, 936	74. 2	1, 627	99. 9
1916	1, 906	89. 7	636	90. 2	1922	2, 820	75. 6	789	44. 7	1927	3, 720	69. 4	3, 192	89. 2

[a] The percentages of survival of the winter-fed and hibernating terrapins are not directly comparable because the hibernating terrapins were taken from the hibernating boxes and counted late in March or early in April, whereas the winter-fed terrapins were counted when removed from the nursery house at least 1 month later. The death rate among hibernating animals during the first month after emerging from hibernation usually is large and generally much greater than among winter-fed animals.

[b] It must not be assumed that the sum of the winter-fed and the hibernating lots of each year equals the total hatch. All the young animals rarely are found in the autumn, and frequently there is a considerable addition in the spring. Such animals, of course, are not included in this table.

[10] Barney (1922, pp. 93 and 94) has attempted to analyze the age of the wild brood stock on hand at this station. He estimated that their average age in 1921 was 28 years. If that be true, they would now (1928) be about 35 years old.

TABLE 18.—*Actual and probable percentage of survival of terrapins at 6 years of age*

Brood	Terrapins originally in brood or lot	Number surviving when selections were made (usually at 8 or 9 months of age)	Number selected and retained	Per cent of lots retained surviving at 6 years of age	Probable per cent of whole brood or lot surviving at 6 years of age	Remarks
1910	173	(1)		83.2		All fed first winter and in part the second. Entire lot retained.
1910	120	(1)		78.3		Hibernating lot, all retained.
1911	100	(1)		82.0		Fed three winters.
1911	100	(1)		78.0		Hibernating each winter.
1912	500	463	100	93.0	86.1	Largest (best) selected from entire lot.
1912	500	463	100	69.0	63.9	Smallest (runts) selected from entire lot.
1913	525	504	100	92.0	88.3	Largest selected.
1914	1,349	661	100	91.0	49.0	Do.
1915	703	(1)		51.1		Missing, 84; probably escaped or carried away by rats or other enemies. This lot was liberated when 5 years of age.
1916	2,006	1,710	200	97.5	83.1	Largest selected.
1917	1,481	910	200	50.5	34.4	Largest selected; many missing.
1918						All liberated soon after hatching.
1919	2,433	1,938	100	78.0	63.9	Largest selected.
1919	214	(1)		61.2		Hybrids; Texas male, North Carolina female.
1919	300	(1)		31.0		Hybrids; North Carolina male, Texas female. Rats destroyed many during first year.
1920	2,503	1,995	337	62.0	52.7	Largest selected, three lots combined.
Average					[2] 60.7	

[1] No selection.
[2] In computing this average, the actual number of terrapins that survived in the unselected lots, as well as the number estimated that would have survived of the lots and broods from which selections were made, were taken into consideration.

TABLE 19.—*Deaths among adult and growing terrapins after an age of 3 years was attained*

Lot	On hand 3 years old	Last counted	Deaths during intervening period	Missing at end of period	Lot	On hand 3 years old	Last counted	Deaths during intervening period	Missing at end of period
1910—Fed	157	1925	13	14	1917—Wide range	63	1927	3	21
1910—Hibernated	96	1925	5	0	1919—Hybrids; Texas male, Carolina female	54	1927	1	1
1911—Fed	84	1926	6	0	1919—Hybrids; Texas females, Carolina male	31	1927	0	0
1911—Hibernated	81	1927	2	3	1919—Domestic stock	87	1927	1	12
1912—Selects	96	1927	6	6	1920—Hybrids; Carolina males, Texas females	64	1927	1	6
1912—Runts	79	1927	3	12	1920—Domestic stock	144	1927	6	24
1913—Selected	94	1927	9	6	Adults—Wild stock, age unknown	[1] 154	1927	9	[2] 29
1914—Selected	96	1926	7	4					
1915—Selected	440	1920	20	82					
1916—Selected	195	1927	6	0					
1917—Close range	52	1927	1	0					

[1] On hand in 1911. [2] Mostly sold.

RATE OF GROWTH

The average length of diamond-back terrapins at hatching is about 27 millimeters (1 1/12 inches), the usual range in size being from 25 to 30 millimeters. Occasionally individuals are hatched that are only 22 to 24 millimeters long, and there is a record of one abnormally small one with a length of only 19 millimeters. The largest one of which we have a record was 31.5 millimeters long.

Newly hatched terrapins do not feed immediately. Those that are left outdoors to hibernate, as in nature, do not take food until they are from 7 to 8 months old; that is, they do not feed in the autumn during which they are hatched. In fact,

some of them do not even leave the "nests." They hibernate during cool and cold weather and generally do not emerge from the shelter in which they have spent the winter until the first warm days of the following spring. Even then they do not feed until the weather gets fairly warm. At Beaufort some of the terrapins generally emerge from hibernation during the latter part of March and others in

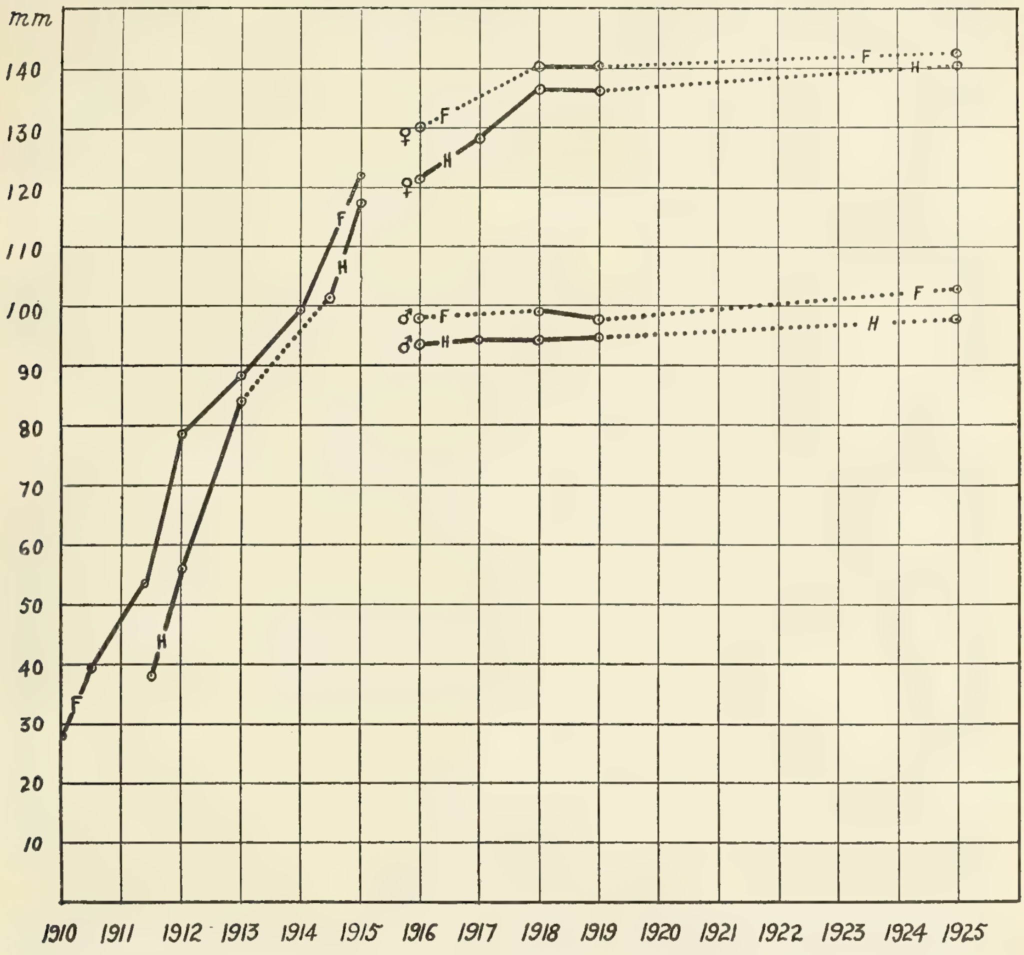

FIGURE 1.—Rate of growth of two unselected lots of the brood of 1910. Line *F* represents a lot that was fed the first and in part the second winter, and line *H* represents a lot that hibernated each winter

April. They do not feed regularly until about the latter part of May and do not make perceptible growth for a month or more after regular feeding takes place.

GROWTH OF YOUNG TERRAPINS KEPT WARM AND FED DURING THE WINTER

Winter feeding experiments were carried on at Beaufort almost from the beginning of the present investigation, and since 1912 a small house especially constructed for this purpose has been in use. This house, a frame structure with a natural sand floor, was provided with a long, gently sloping glass roof on the south side, which

admitted direct sunshine to most of the floor space during the greater part of the day. The animals were held in water-tight wooden boxes or tanks (a few metal tanks also were used) from 8 to 10 feet long and 20 to 24 inches broad. These tanks were divided into four or five compartments. Each tank was tilted to one side, and enough water was supplied to cover about half of the bottom of each compartment. This arrangement made it possible for the animals to enter the water or to stay out, according to choice. The house was heated by a stove.

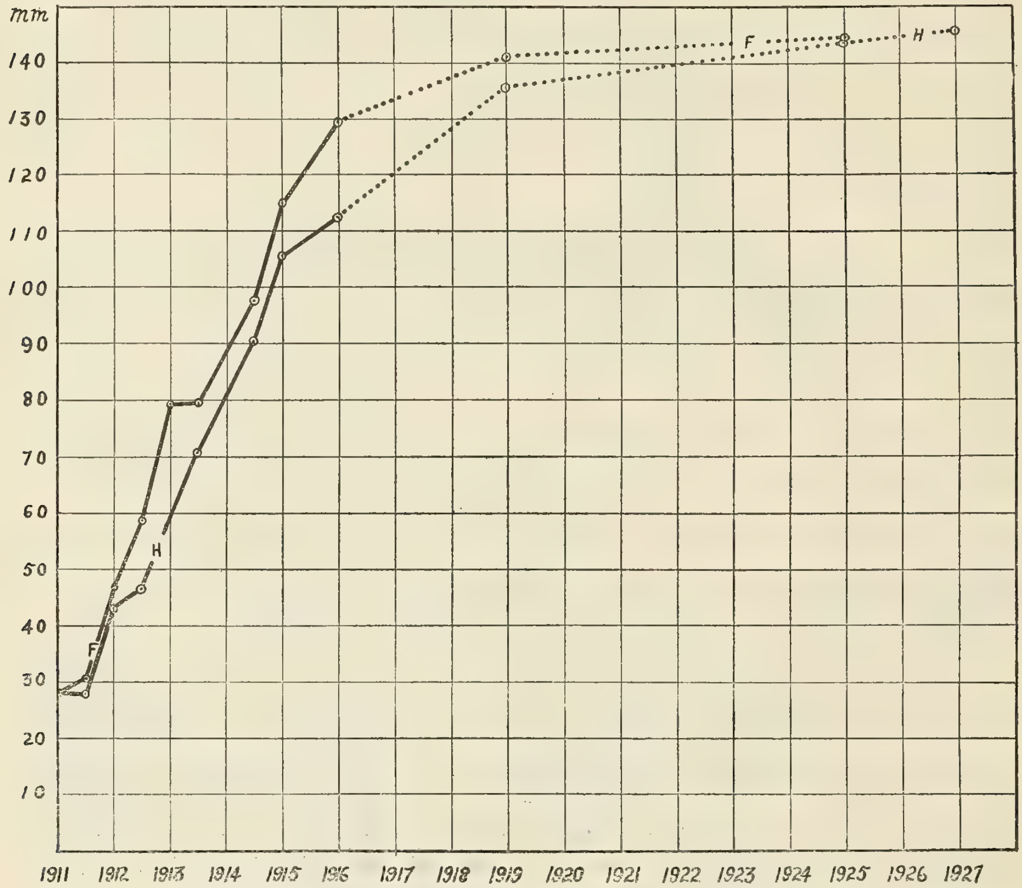

FIGURE 2.—Rate of growth of two unselected lots of the brood of 1911. Line *F* represents a lot that was fed the first three winters, and line *H* represents a lot that hibernated each winter. No males were present in either lot

Generally, young animals were placed in the brooder house in October, and an effort was made to keep the temperature at or above 80° F. in so far as possible with such an inefficient heating plant as a stove. Under these conditions terrapins remain active all winter.

Recently hatched young, only, were winter fed, except a lot of the 1910 and another of the 1911 brood, which were fed, respectively, two and three winters. The gain in growth during the winter of terrapins that were over a year old was so small that winter feeding of all except the recently hatched young was abandoned because it appeared to be impracticable.

A small percentage of the terrapins placed in the brooder house begin to take food almost immediately, others will not eat for several weeks, and still others apparently never eat. Those that start to feed first also begin to grow earlier than the others. In general, very little growth is made, however, prior to the month of December. The animals that do not appear to feed at all for a long period of time become more and more sluggish, they become emaciated, and the shells gradually soften, causing what is described as "soft shell" under another section of this report. The death rate from this source, as shown elsewhere, has been heavy. It is remark-

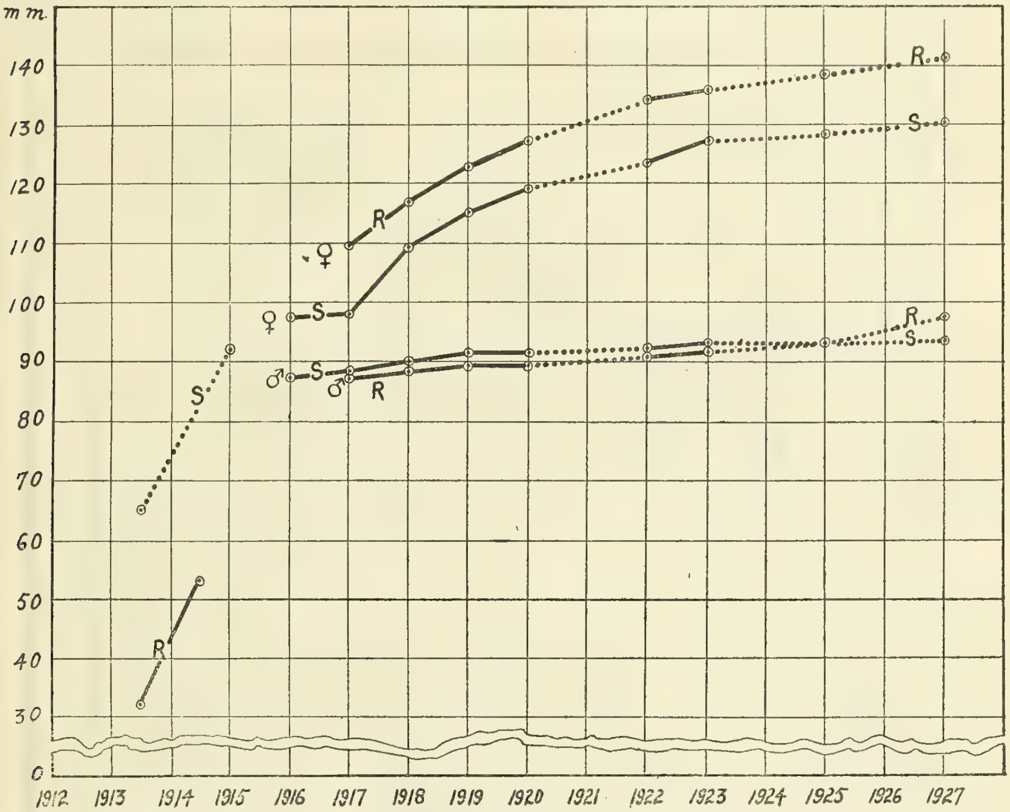

FIGURE 3.—Rate of growth of two lots of terrapins of the brood of 1912. Line *S* represents a lot that was selected at about 1 year of age as the largest, and line *R* represents a lot selected at the same time as the smallest (runtiest) in the whole brood

able, however, that some of these animals that appear to have subsisted for months upon food stored within their bodies or, as it were, upon their own substance, until they are pitiful objects, may suddenly take food and thereafter make rapid growth and become strong and healthy animals. Elsewhere in this report (p. 40) it is shown that of 200 such animals selected during the latter part of May, 1927, which had never gained growth and which, so far as known, had never taken food although it had been supplied almost daily, 74 recovered without providing a change in food or in the environment in which they were living. Animals that have once fed occasionally

cease feeding and in that event also become emaciated and gradually acquire a soft shell. The sudden change in the rate of growth of animals that have made little or no growth is further discussed in connection with the brood of 1912.

Animals in hibernation, of course, make no growth, but subsist upon foods stored within the body. Such animals are poor when they emerge and generally have to feed for a month or more, as already stated, before perceptible growth is made. This is especially true of terrapins in their first year, and that is one of the reasons why winter feeding of recently hatched young appears to be profitable.

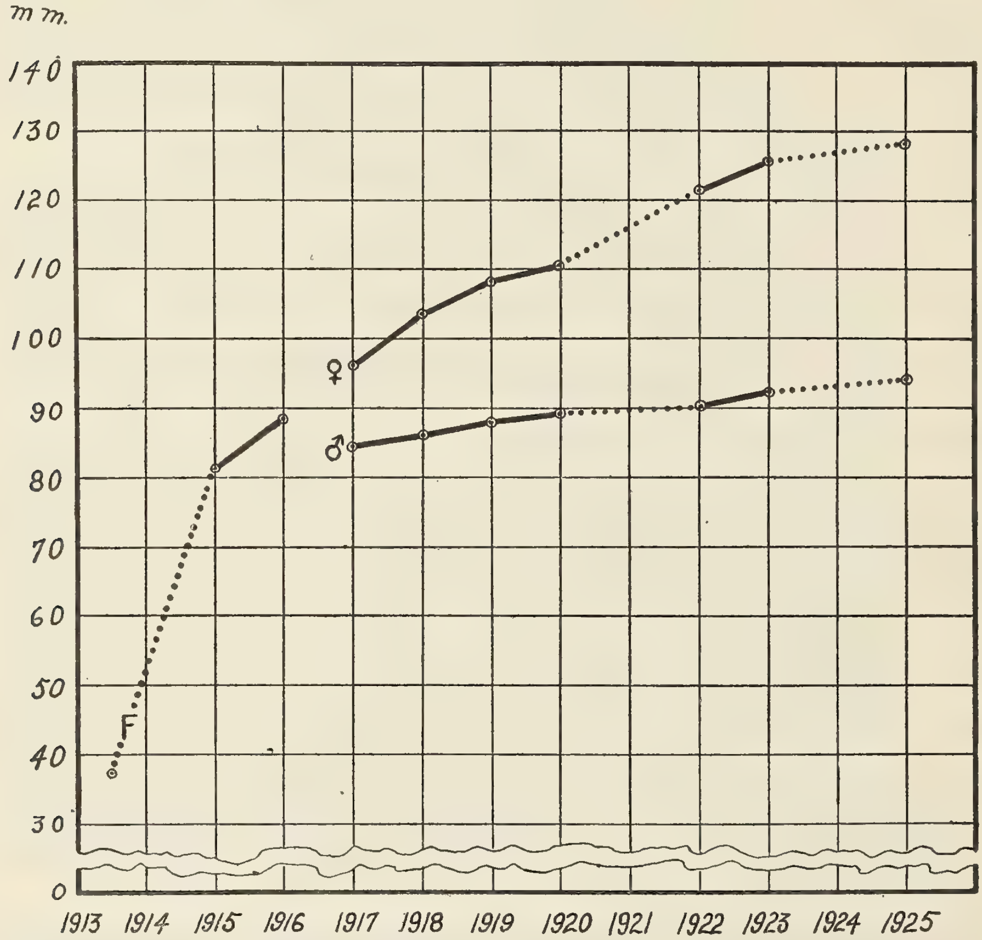

FIGURE 4.—Rate of growth of a selected lot of the brood of 1913

The rate of growth of the winter-fed lots while in the nursery house—that is, until they are about 8 months old—has varied greatly, as shown by Table 20. The small lot of the brood of 1910, consisting of only 173 animals, the first one fed during the winter, was among the best produced to date (1928); for the average length of the terrapins was 39.7 millimeters (representing a gain of 11.6 millimeters) when they were removed from winter quarters on May 10, 1911 (Table 22). Small lots of 100 or so, held in separate compartments in the terrapin house, have done equally

as well or slightly better, but the greatest gain made by a large lot occurred in the 1916 brood, when 1,040 animals reached an average length of 39.2 millimeters on

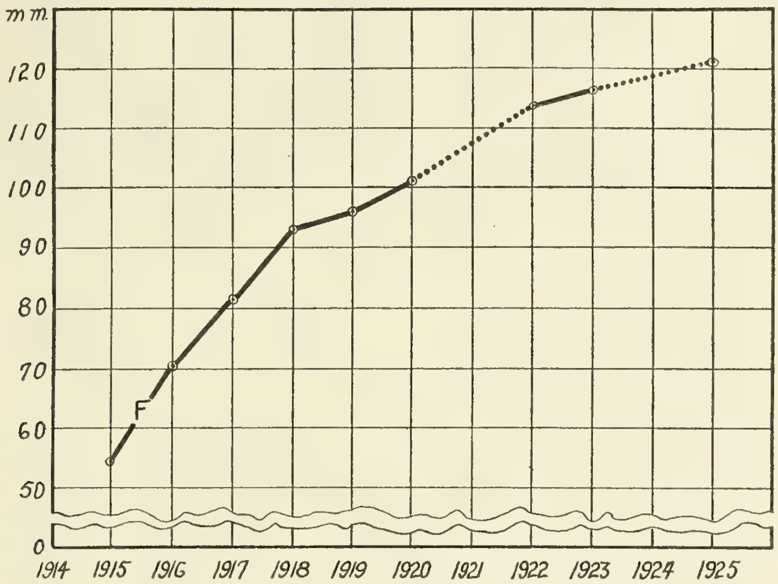

FIGURE 5.—Rate of growth of a selected lot of the brood of 1914

May 25, 1917, when they were removed from winter quarters. The least growth attained to date occurred in the broods of 1911 and 1923, the animals in each brood, upon removal from winter quarters, being found to have reached a length of only 30.9 millimeters.

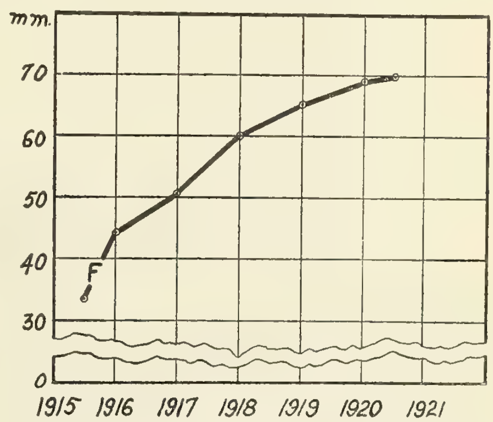

FIGURE 6.—Rate of growth of a large lot of the brood of 1915. This lot was discarded in the spring of 1921

The average rate of growth of the 1923 brood, as in several other broods, quite probably was considerably reduced because of experimentation with different kinds of foods and various kinds of treatment. For example, some of the animals of the brood of 1923 were fed salted fish, which proved to be less acceptable to the terrapins than fresh fish or oysters and produced slower growth. Then, too, some of the animals, for the purpose of experimentation, were greatly crowded in the tanks in which they were held, and that appears to have retarded growth. The different kinds of foods used and their relative value, as well as the different conditions with respect to crowding, heat, water supplied, etc., are discussed elsewhere in this section. It appears to be sufficient to state at this point that a considerable number of experiments were run and that several of them actually retarded growth, which, however, was not unexpected.

If the sole aim had been to produce the greatest gain possible, a much better average rate of growth undoubtedly could have been produced.

The excellent growth made by the winter-fed lot of the 1910 brood is noteworthy, especially because of the seemingly unfavorable conditions under which it was held. A special house, as already indicated, was not yet available. Therefore, the animals were placed in the pump house at the station. The tanks were so arranged with respect to the windows that they received the rays of the sun through the window glass during a part of the day. No special heating plant was provided. Some heat, however, was obtained from the steam boiler used for pumping water, but the boiler was used only intermittently and not every day. On especially cold days some

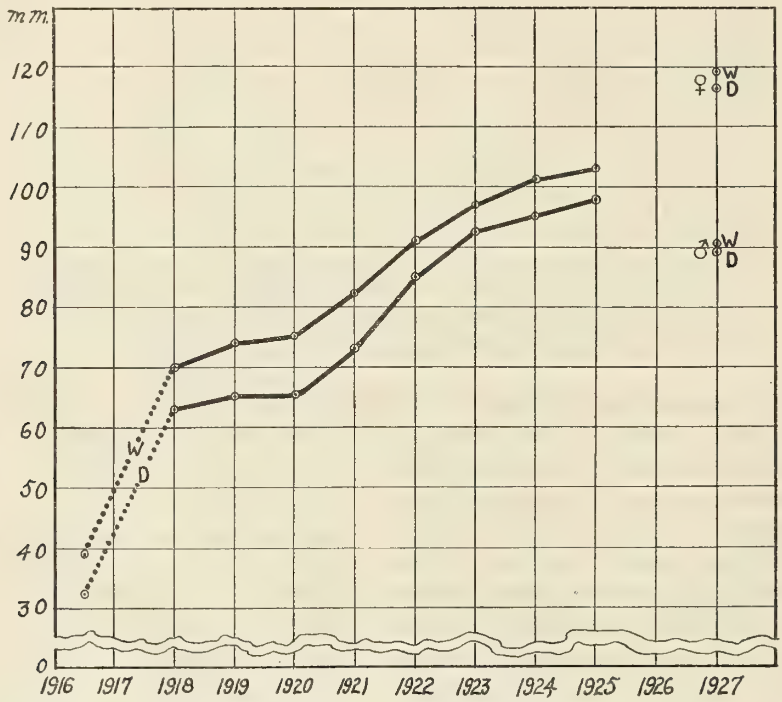

FIGURE 7.—Rate of growth of two lots of selected terrapins of the brood of 1916. Line *D* represents offspring of domestic stock and line *W* that of wild stock

extra heat was supplied from oil stoves that were run only on such occasions. It is quite remarkable, in the light of present knowledge, that such excellent results were obtained under these circumstances, and furthermore, as shown elsewhere, the death rate was extremely low. A part of the next brood (that of 1911) was kept under identical conditions, and although the death rate remained remarkably low, the rate of growth, as already indicated, was as low as it has been to date (1928) for any winter-fed lot. Somewhat similar fluctuations with respect to growth, as shown by Table 20, have taken place from year to year. They have occurred, also, within a brood among animals of the same parents and not infrequently among the small lots held in adjoining compartments of the same tank, receiving identical treatment. It is impossible, as yet, to explain the reason or reasons for all fluctuations.

In general, those animals that were nearest the stove where the temperature was the highest and probably somewhat more uniform than elsewhere made the greatest growth. On the other hand, those held in certain tanks rather far removed from the stove and placed in such a position that the animals received no direct sunshine invariably made the least growth.

Various methods of sanitation (some of which are described in the section of this report dealing with the records of survival) have been employed, but apparently without appreciable effects upon the rate of growth.

One metal (galvanized iron) tank has been used for several years. The animals in this tank, which was always placed near the stove, gained a fair to a good rate

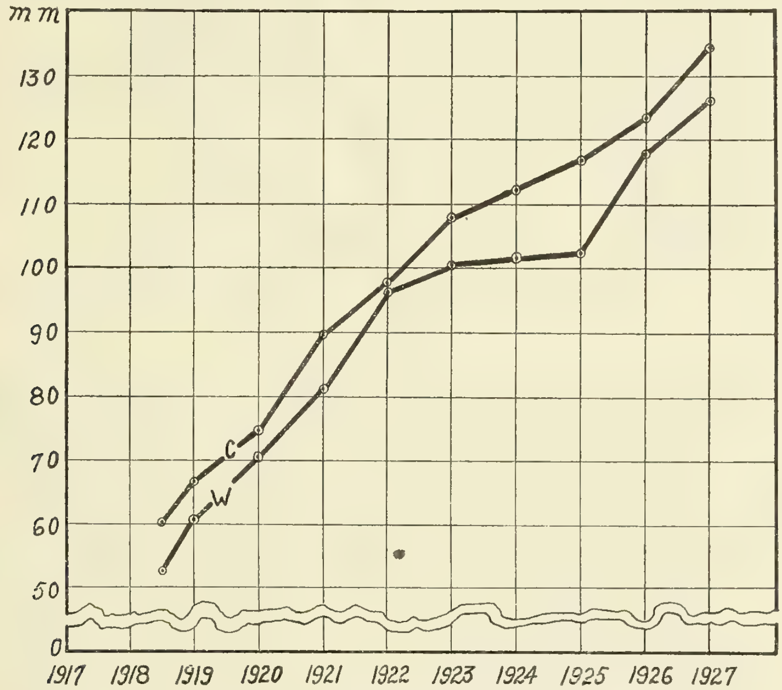

FIGURE 8.—Rate of growth of two lots of terrapins of the brood of 1917. Line *C* represents the lot under close "range" and line *W* the lot under a wild "range"

of growth during certain years, and again the gain was quite small. The average rate of growth of the animals held in this tank during the period 1920 to 1926, compared with that of animals held in adjoining tanks during the same period of time, is just about equal; that is, the average size of 1,018 animals held in the metal tank during the period indicated was 32.5 millimeters, whereas it was 32.3 millimeters for 1,195 animals held in a wooden tank placed at one side of it, and 32.9 millimeters for 973 animals in another wooden tank on the opposite side. The metal tank, as indicated elsewhere, did not bring a lower death rate, for in this respect the results also are intermediate of those for the adjoining tanks. A metal tank is kept clean somewhat more easily, and this apparently is the only advantage it has over a wooden one. On the other hand, galvanized iron corrodes in a comparatively brief

period of time in this climate and does not last so long as wood. Other metals and enamel are regarded as rather too expensive for economical use.

TABLE 20.—*Average size of terrapin fed during their first winter*

Brood	When measured	Number measured	Average length in millimeters	Remarks
1910	May 10, 1911	173	39.7	
1911	Apr. 23, 1912	216	30.9	
1912	May 5, 1913	463	31.8	
1913	Apr. 29, 1914	504	31.0	
1914	May 24, 1915	351	32.9	Fed fresh fish and oysters.
1914	do	376	31.5	Fed salted fish.
1915	Mar. 15, 1916	662	33.8	Fed fresh fish and oysters.
1915	do	613	29.9	Fed salted fish.
1916	May 17-25, 1917	1,040	39.2	
1917	May 15, 1918	1,045	31.1	
1919	May 11, 1920	290	33.7	Hybrids, Texas and Carolina terrapins.
1919	do	169	34.9	Offspring domestic stock.
1919	do	158	36.0	Offspring wild stock.
1920	May 13, 1921	1,994	31.8	
1921	May 16, 1922	2,101	31.7	
1922	May 23, 1923	2,132	32.2	
1923	May 16, 1924	2,054	30.9	
1924	May 11, 1925	1,651	32.3	
1925	May 13, 1926	2,019	32.4	
1926	May 12, 1927	2,180	31.7	
1927	May 7, 1928	2,583	30.8	
Average			32.4	

FOOD

The following foods have been supplied: Fresh and salted fish, oysters, clams, and crabs. Vegetables have been offered at different times but were not eaten. A comparison of the utility of the various foods can not yet be given because of the unequal distribution of heat in the terrapin house. It is pointed out elsewhere that the greatest amount of growth almost invariably was made by the terrapins nearest the stove. This is true, in a measure, regardless of the food supplied or other treatment given. This factor, therefore, evidently is an important one, and a comparison of the rate of growth with respect to the foods supplied is not a fair one unless the animals were similarly situated with respect to the source of heat. As far as possible such comparisons have been made but are considered of only limited value, and only general discussions are given. It remains for future investigation to determine the actual value of the various foods that are available and that seem suitable, and that can be done only when a house becomes available in which uniform temperatures can be provided.

Fresh fish was used much more extensively than the other foods that have been mentioned, because (next to salted fish) it was the most convenient and economical to use and the growth attained apparently was exceeded slightly only when oysters were fed. Salted fish (mullet) was not taken readily. In fact, terrapins that had been feeding on fresh food had to be starved for a week or two before they would take salted fish. It is not surprising that animals fed with this apparently distasteful food grew slowly. Crabs appear to be a good food and are taken readily, but they are so difficult to get during at least a part of the winter that it was found impracticable to feed them continuously. Clams are taken readily but have not been supplied over long periods of

time and are regarded as too expensive to use in practical terrapin culture. Oysters, also, are regarded as too expensive to use extensively, even though they produce rapid growth in the young animals. Although definite data are not available, it would appear advantageous to supplement fresh fish from time to time with oysters, clams, and crabs.

CROWDING

Various degrees of crowding have been tried in the tanks in the brooder house with the view of determining the space requirements of the young animals. In this series of experiments, which extended over three seasons (October to May, 1923 to 1926), tanks 8 feet long and 20 inches broad, divided into four compartments, were used. Each compartment, therefore, had a floor space of about 20 by 24 inches.

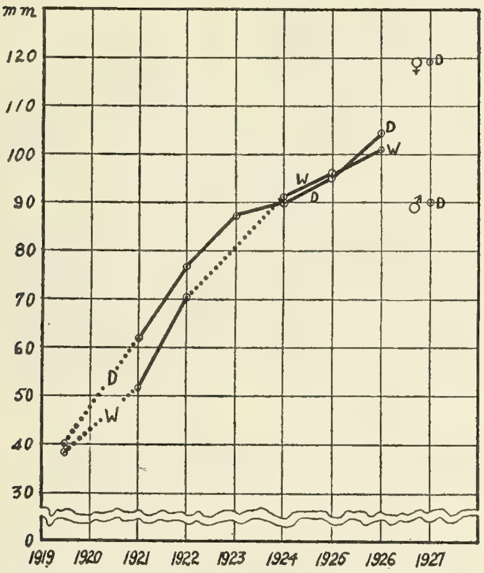

FIGURE 9.—Rate of growth of two lots of terrapins of the brood of 1919. Line *D* represents offspring of domestic stock and line *W* offspring of wild stock

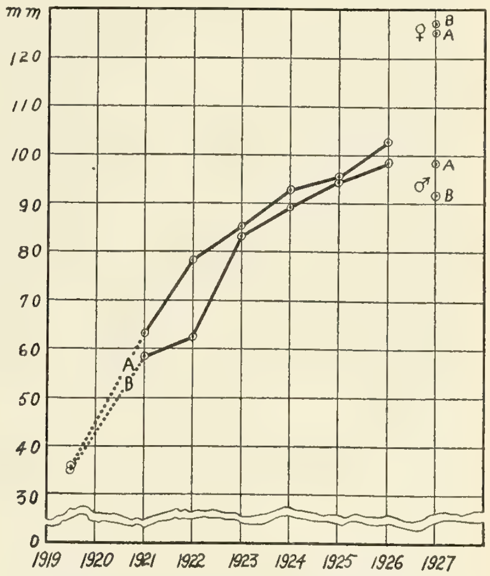

FIGURE 10.—Rate of growth of two lots of hybrid terrapins of the brood of 1919. Line *A* represents a cross between Texas males and North Carolina females, and line *B* represents a cross between Carolina males and Texas females

In some of the compartments 25 to 50 animals were confined, in others 100 were held, and in still others from 125 to 150 were placed. The rate of growth appears to be slightly in favor of the least crowding, for the average length of the 260 animals that survived was 34.8 millimeters. For the next degree of crowding, namely 100 animals to a compartment, the average size of 877 surviving animals was 33 millimeters, and for 1,082 surviving animals crowded to the extent of 125 to 150 to a compartment the average length attained was 31.1 millimeters. It is shown elsewhere that a somewhat similar relationship with respect to the rate of survival existed for the different groups of crowding. It appears reasonable to conclude, therefore, that it is feasible and economically advantageous to hold as many as 100 young animals in a tank having a floor space of about 20 by 24 inches, but greater crowding appears to result in higher mortaility and slower growth.

COMPARISON OF THE SIZE OF WINTER-FED AND HIBERNATING TERRAPINS AT ABOUT 1 YEAR OF AGE

It has been shown that young terrapins were kept active and were induced to feed during the winter when they were placed in a warm house. Under such conditions the average gain in length per year over a period of 17 years ranged from about 4 to slightly over 11 millimeters, the average gain for all winter-fed terrapins (20,034) being 5.7 millimeters. During this time the hibernating terrapins, of course, are making no growth. Table 21 shows the difference in size of winter-fed and hibernating animals at about 1 year of age for six pairs of lots of six different broods. The winter-fed animals of all lots combined (1,069 animals) had an average length of 44.1 millimeters, whereas the hibernating animals (780) had an average length of 37.5 millimeters. This advantage in growth appears to have been maintained fairly well in those lots that were grown to maturity in confinement.

The gain in growth during their first winter of the animals that were fed represents about a year's growth. This lead in size over hibernating terrapins is important in terrapin farming, as it would hasten the turnover by just that length of time. Furthermore, sexual maturity was reached a year earlier and, as stated elsewhere, the death rate apparently was considerably lower. Winter feeding, when terrapin culture is engaged in for the purpose of reestablishing or augmenting the supply in nature, offers the advantage that most of the young will have gained considerable growth and will have passed through the most critical stages of life at about 8 months of age, when they may be liberated with the assurance that they stand a fair chance of survival. On the other hand, it has been considered advisable at Beaufort to retain the hibernating terrapins a year longer, involving extra care and work and a greater mortality.

TABLE 21.—*Comparison of size of winter-fed and hibernating terrapins at about 1 year of age*

Brood	When measured	Winter-fed			Hibernating		
		Number measured	Total length	Average length	Number measured	Total length	Average length
1910	Apr. 15, 1912	[1] 105	5,614	53.4	[1] 104	3,954	38.0
1911	Sept. 9, 1912	95	4,464	47.0	89	3,833	43.0
1923	Oct. 9, 1924	241	9,424	39.1	163	5,350	32.8
1924	Oct. 27, 1925	262	11,074	42.2	122	3,977	32.5
1925	Oct. 5, 1926	228	9,097	39.4	206	7,469	36.2
1926	Sept. 27, 1927	138	7,531	54.4	96	4,686	48.7
Total		1,069	47,204	44.1	780	29,269	37.5

[1] These animals were not measured at 1 year of age. However, the measurements were taken the following spring before the terrapins had started to make new growth, and the sizes here given of course, are the same as they would have been the preceding autumn, or at the age of 1 year.

GROWTH OF TERRAPINS PAST 1 YEAR OF AGE

It has been pointed out already that the rate of growth of terrapins during their first year is very irregular both among broods and within single broods. This irregularity in size and rate of growth is equally pronounced in the older terrapins that are being grown in captivity. It does not follow, however, that those animals that grow slowly at first will continue their slow growth and always be "runts." If that were the case, the runts would not constitute the serious problem they are to the terra-

pin culturist, for then they could be eliminated at an early age and before they had become much of a liability. It is not practicable to do this, however, for frequently the slow-growing animals suddenly begin to grow fast and in a comparatively brief time overtake those that grew fast earlier in life but discontinued their rapid growth.

An excellent example of the changes in the rate of growth of terrapins is found in the brood of 1912 (Table 24). In this instance, from a total of about 800 yearling animals 100 of the largest were selected and placed in a separate pen; also 100 of the smallest and runtiest were selected and placed in an adjacent pen. Food and treatment and the general environment were made as nearly identical as possible. Measurements of the two lots at the time of selection (September 13, 1913) are not available. The animals were measured in the following spring (April 29, 1914), however,

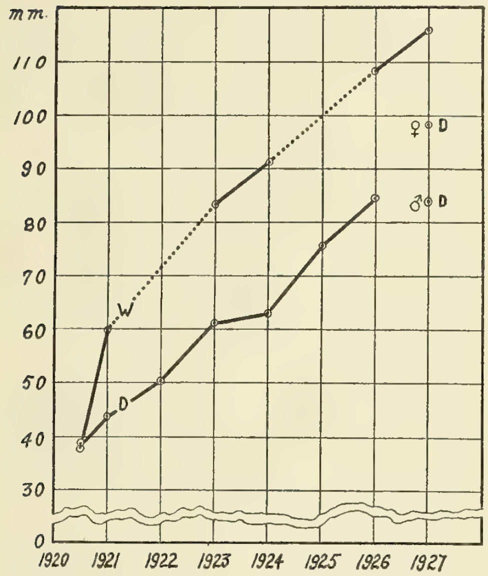

FIGURE 11.—Rate of growth of two selected lots of the brood of 1920. Line *D* represents offspring of domestic stock and line *W* that of wild stock

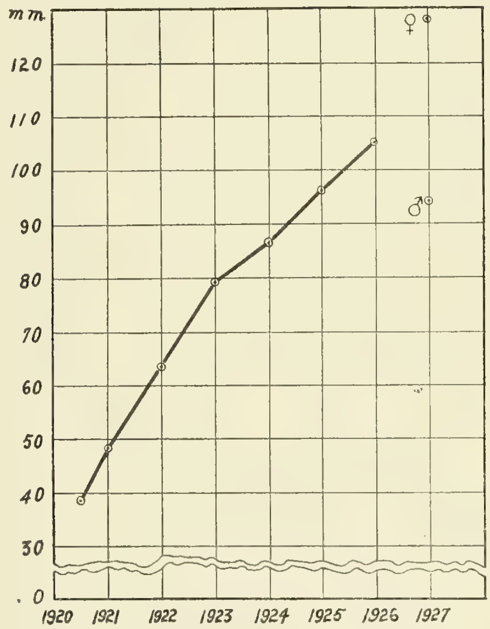

FIGURE 12.—Rate of growth of an unselected lot of hybrid terrapins (Carolina males and Texas females) of the brood of 1920

and of course not much growth had taken place during the interval. The 100 "selects" all survived until spring and had an average length of 65 millimeters. The 100 "runts" had diminished to 89, and these animals had an average length of 32.3 millimeters. On October 6, 1917, the selects, which then numbered 89, consisted of 18 males and 72 females. The males had an average length of 88.7 millimeters and the average length of the females was 98 millimeters. On the same date the runts numbered 69 and were composed of 13 males and 56 females. The males averaged 87.2 millimeters in length and the females 109.5. The combined average length of male and female "runts," therefore, was greater than that of the "selects." The lead then secured by the "runts" has been maintained to the present time (1928).

It is not known that identical results would be obtained if a similar experiment were to be undertaken. The selection experiment with the brood of 1912, together

with others of much shorter duration, offer sufficient evidence, however, to show that it is not practicable to make selections of fast growing terrapins at 1 year or less of age. Furthermore, it seems very probable that such selections can not be made even at 2 or possibly at 3 years of age. The data on this last point still are quite meager. The fact that some animals (as is plainly shown by the accompanying tables) grow very slowly and require a much longer time than others to reach maturity and a size sufficiently large to make them valuable on the market, however, is well established, and these extremely slow growing individuals appear to furnish the chief obstacle to terrapin farming as an enterprise.

Comparatively few females [11] (as shown by the tables presented herewith) reached sexual maturity and a length of 5½ inches at the age of 5 years. A somewhat larger percentage reached it at 6 years of age. However, 9.8 per cent of the females of the winter-fed lot of the 1910 brood were still under that size at the age of 15 years. Among the hibernating lot of the same brood, 19.5 per cent were under 5½ inches in length at the same age. Although marketable at a smaller size, a terrapin is not considered a "count" and does not bring a fancy price until it has reached a length of 6 inches or more. According to this classification only 28.5 per cent of the winter-fed lot of the 1910 brood and 25.2 per cent of the hibernating lot of the same brood would have passed as counts at the age of 15 years.

In the 1911 brood 12.9 per cent of the animals (no males included) of the winter-fed lot were less than 5½ inches in length at 14 years of age, and in the hibernating lot of the same brood 15.2 per cent were under this size at 14 years of age. The percentage of counts was somewhat greater than in the 1910 brood, for 41 per cent of the fed lot and 45.8 per cent of the hibernating lot could have been classed as counts at 14 years of age. Younger broods have made even slower growth.

The growth curves presented herewith show that, in general, the average rate of growth is fairly rapid until the terrapins reach an age of 5 or 6 years. Thereafter it becomes much slower, and after the eighth to the tenth year it is extremely slow. The almost negligible growth of the older animals, as, for example, those of the 1910 brood, after attaining an age of about 8 years suggests that some of the animals will never reach a length of 6 inches. It seems improbable, even, that all of them will reach 5½ inches. In the winter-fed lot of the 1910 brood, for example, 11 of the 102 females included were less than 5½ inches long, the smallest one having a length of only 4 4/5 inches when last measured at the age of 15 years. In the hibernating lot of the same brood, at the same age, 17 of the 87 females included were less than 5½ inches long, and the 2 smallest ones were only 5 inches in length. The first-mentioned lot, according to our records, appears to have made an average gain in growth of only 2.5 millimeters, and the other lot only 4 millimeters during the six years prior to the last measurements, or between the ages of 9 and 15 years.

In the winter-fed lot of the 1911 brood, 10 of the 78 females included were under 5½ inches long, the smallest one having a length of 4 4/5 inches when last measured at the age of 14 years. Among the hibernating lot of the same brood at the same age 11 of the 72 females were less than 5½ inches long, and the smallest one was 5⅛ inches in length. The winter-fed lot had made an average gain of 3.4 millimeters

[11] The males are not considered in this connection as none of them appear ever to reach as great a length as 5½ inches, and they reach sexual maturity at a much smaller size.

and the hibernating lot a gain of 8.9 millimeters during the 6 years prior to the last measurements, that is, between the ages of 8 and 14 years.

The data presented in the foregoing paragraphs are illustrative of the extremely slow growth that is made by terrapins that are 8 to 10 years or more of age, and they suggest, as already indicated, that some females will never reach a length of 6 inches and that a small percentage may not even reach 5½ inches. It appears to be of interest to note that among the original wild brood stock confined, part since 1909 and part since 1911, and with few exceptions "adult" terrapins when secured, 17 females were under 6 inches in length when last measured (1925). It would seem almost certain that such animals will never reach a length of 6 inches. It is not surprising, therefore, that all females grown in captivity apparently do not reach a length as great as 6 inches. In commercial terrapin growing it probably would not be profitable to retain the animals after comparatively rapid growth ceases; that is, after an age of 8 to 10

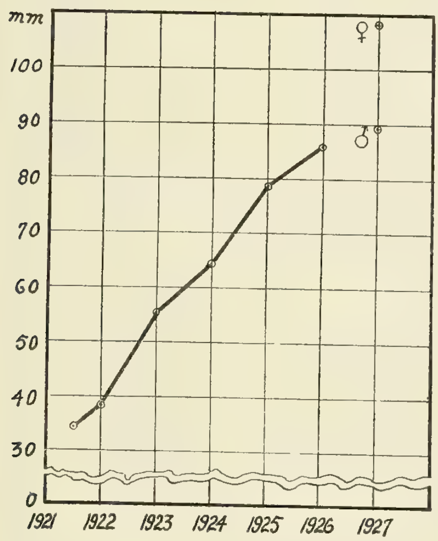

FIGURE 13.—Rate of growth of a selected lot of the brood of 1921

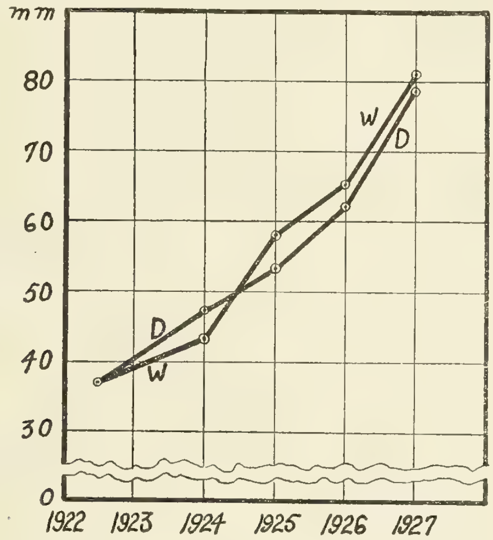

FIGURE 14.—Rate of growth of the brood of 1922. Line *D* represents offspring of domestic and line *W* of wild stock

years is reached. A considerable percentage of the terrapins at these ages, as shown by the accompanying tables, are 5 inches and over in length and would bring a fair price on the market, and it seems doubtful if the increment in size thereafter would justify the expense of food and labor involved to produce it.

The largest size attained to date by any terrapin grown in captivity is 6⅝ inches. It is well known, of course, that in nature individuals measuring 7 inches and over in length occasionally are taken. A single female occurs among the wild brood stock confined at this station having a length of slightly less than 7½ inches (185 millimeters). This animal probably approaches the maximum size attained by Carolina terrapins. The Texas terrapins, of course, grow somewhat larger and occasionally slightly exceed a length of 8 inches.

Information relative to the rate of growth of terrapins in nature virtually is wanting. A few animals hatched at this station and liberated at about 1 year

of age have been retaken. The recaptured animals had gained growth at about the same rate as the fastest growing ones of the same age that were raised in captivity. In the almost total absence of data on the rate of growth in nature, a comparison of the rate of growth of domestic and wild animals can not be given. Neither will it be known, until much more information is obtained, whether an equally large percentage of wild animals are slow growers or runts as among domestic ones. Therefore, it is not yet known what influence, if any, domestication has on the rate of growth.

Male terrapins have been omitted in the discussions on growth because they do not reach a large size and are of comparatively little value on the market. The sexes can not be distinguished in young terrapins until a length of about 3 inches or more is attained. For this reason the sexes are not listed separately in the accompanying tables until they have attained a considerable size. It is not evident that there is a difference in the rate of growth with respect to the sexes until they become distinguishable. Thereafter the males appear to grow less rapidly, and consequently they are soon much smaller than the females. It is fortunate, from an economic point of view, as pointed out eleswhere, that the males appear to be greatly in the minority, for the largest one of which a record is on hand was 4⅝ inches long and the largest one among the domestic animals has a length of only 4½ inches. The average size of adult males appears to be around 4 inches, and a considerable percentage apparently never exceeds a length of 3¾ inches.

CONCLUSIONS

It is evident from the foregoing discussion and the data presented that the chief problem of the terrapin culturist is the elimination of the runty and slow-growing animals. It has been shown that this can not be done through selection at an early age. Therefore, the problem apparently must be solved, if in fact it can be solved, through selective breeding. Experiments along that line are under way, but owing to the slow growth and the long time it takes terrapins to mature no definite results have been obtained to the present time (1928). Slow growth, late maturity, and animals of comparatively small size may not be of importance in the case of terrapins that are liberated and attain their growth in nature, but they are of extremely great importance to the terrapin farmer, who would of necessity be interested in as quick a turnover as possible and in the production of large animals that would bring a fancy price on the market. It has been shown that little growth is gained after the animals reach an age of 8 to 10 years, and the writer believes that it would not be profitable in terrapin farming to retain the animals longer, but that they should be disposed of at about that age regardless of size.

TABLE 22.—*Rate of growth of the brood of 1910*

When measured	Winter fed					Hibernating				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
October, 1910	171	25	31	----------	[1] 28.1	----------	----------	----------	----------	----------
May 10, 1911	173	28	61	----------	39.7	----------	----------	----------	----------	----------
Feb. 9 to Apr. 22, 1912	105	35	78	----------	53.4	104	29	49	----------	38.0
Sept. 9, 1912	161	41	98	----------	78.7	98	----------	----------	----------	56.5
July 2, 1913	----------	----------	----------	----------	----------	94	38	90	----------	68.5
Sept. 10, 1913	157	52	122	----------	88.4	97	62	105	----------	84.4
Apr. 30, 1914	153	52	124	----------	99.4	97	62	105	----------	84.4
Apr. 12, 1915	----------	----------	----------	----------	----------	94	83	118	----------	101.8
Oct. 5, 1915	143	83	154	71	122.1	95	89	137	19	117.6
Aug. 29, 1916: [2]										
Male	16	84	107	95	98.0	5	90	96	41	93.4
Female	127	100	154		130.1	89	99	147		121.4
Oct. 3, 1917:										
Male	----------	----------	----------	----------	----------	5	91	97	55	94.2
Female	----------	----------	----------	----------	----------	78	101	152		128.2
Sept. 13, 1918:										
Male	17	85	108	111	98.8	5	91	97	83	94.2
Female	129	117	165		140.3	89	112	156		136.7
Sept. 20, 1919:										
Male	18	85	[3] 109	123	[3] 97.7	5	92	97	86	[3] 94.8
Female	129	120	164		140.1	89	114	158		136.4
Oct. 21, 1925:										
Male	11	88	112	101	102.7	5	96	100	87	97.8
Female	102	123	165		142.6	87	127	163		140.4

[1] The average size of newly hatched terrapins, according to more recent measurements, is about 27 millimeters. This difference between the early and more recent measurements very probably is the result of the methods used. The recent measurements were made with calipers, whereas the early ones were made with an ordinary rule and are therefore less accurate.

[2] Some of the males, but not all, were distinguishable prior to this date.

[3] The apparent slight decrease in size may be due in part to a closer measurement, but it is more probable that the terrapins measured in 1918 and 1919, in part, were not the same ones, as all the terrapins in any one pen seldom are found at one time.

TABLE 23.—*Rate of growth of brood of 1911* [1]

When measured	Winter fed					Hibernating				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
Sept. 10, 1911	100	25	30	----------	[2] 28.1	100	25	30	----------	[2] 28.1
Apr. 23, 1912	98	25	38	----------	30.9	98	24	31	----------	27.9
Sept. 9, 1912	95	29	68	----------	47.0	89	30	59	----------	43.1
May 21, 1913	86	41	79	----------	58.8	86	31	63	----------	46.8
Sept. 12, 1913	83	47	102	----------	79.1	84	42	88	----------	64.6
Apr. 29, 1914	82	49	105	----------	79.5	81	51	89	----------	71.8
Mar. 23, 1915	78	65	120	----------	97.7	77	64	110	----------	90.5
Oct. 5, 1915	81	96	145	33	115.0	78	83	131	5	105.8
Sept. —, 1916	82	94	155	49	129.8	78	85	141	19	112.4
Sept. 26, 1919	82	110	162	82	141.2	78	107	159	70	135.7
Oct. 16, 1923	----------	----------	----------	----------	----------	74	116	162	38	140.7
Oct. 29, 1925	78	120	165	107	144.6	72	110	164	35	143.6
Oct. 21, 1927	----------	----------	----------	----------	----------	72	129	164	35	145.6

[1] The two lots of the 1911 brood contain no males.

[2] The average size of newly hatched terrapins, as shown, is about 28.1 millimeters (1⅛ inches).

TABLE 24.—*Rate of growth of the brood of 1912*

When measured	Selects [1]					Runts [2]				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
Apr. 29, 1914	100	51	83		65.0	89	27	42		32.3
Nov. 5, 1915	94	76	110		92.0	82	30	82		53.2
Sept. 7, 1916: [3]										
Male	19	81	98		87.2					
Female	77	77	119		97.6					
Oct. 11, 1917:										
Male	18	82	98		88.7	13	80	95	9	87.2
Female	72	82	130		98.0	56	77	136		109.5
Sept. 30, 1918:										
Male	18	85	100	6	90.0	13	83	94	17	88.3
Female	73	88	131		109.7	56	100	145		117.0
Oct. 1, 1919:										
Male	18	[4] 83	[4] 99	19	91.8	12	83	95	34	89.7
Female	75	[4] 87	139		115.1	56	[4] 95	149		123.0
Oct. 5, 1920:										
Male	17	83	100	27	[4] 91.6	13	83	95	39	[4] 89.6
Female	75	89	143		119.0	55	108	151		127.1
Dec. 12, 1922:										
Male	18	83	100	32	92.3	12	84	97	48	91.0
Female	[4] 73	97	145		123.7	55	118	153		134.0
Oct. 10, 1923:										
Male	18	85	101	38	93.4	12	85	98	50	91.7
Female	70	111	146		127.1	55	122	155		135.9
Oct. 21, 1925:										
Male	17	85	[4] 100	48	93.8	12	87	102	55	93.9
Female	69	[4] 106	148		128.6	55	125	155		138.2
Oct. 15, 1927:										
Male	17	86	102	63	94.0	11	90	[4] 101	55	97.7
Female	67	115	151		130.7	54	126	158		141.1

[1] "Selects"; 100 best selected from entire brood, Sept. 13, 1913.
[2] "Runts"; 100 poorest selected from entire brood, Sept. 13, 1913.
[3] The sexes could not be distinguished definitely prior to this date.
[4] The apparent decrease in size may be due to a somewhat closer measurement, or it may be that the same terrapins were not measured, for all the terrapins in 1 pen often are not found.

TABLE 25.—*Rate of growth of the brood of 1913*

When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Remarks
		Mm.	*Mm.*		*Mm.*	
Apr. 29, 1914	686	22	32		27.6	Hibernated.
Do	504	23	48		31.1	Fed first winter.
Do	100	34	48		37.5	Selected best from preceding lot; measurements based on 100 largest.
Nov. 5, 1915	96	69	104		81.1	
Sept. 20, 1916	94	73	112		88.6	
Oct. 11, 1917:						
Male	4	77	95	1	84.5	Prior to this date the sexes could not be separated definitely.
Female	90	76	125		96.0	
Oct. 1, 1918:						
Male	4	80	[1] 89	3	86.0	
Female	90	83	134		103.7	
Oct. 1, 1919:						
Male	4	80	100	10	88.0	
Female	88	86	138		108.3	
Oct. 13, 1920:						
Male	4	81	101	11	89.2	
Female	86	88	140		110.7	
Dec. 12, 1922:						
Male	4	82	[1] 100	29	90.2	
Female	85	95	144		121.2	
Oct. 10, 1923:						
Male	4	85	101	59	92.2	
Female	79	102	148		125.5	
Oct. 21, 1925:						
Male	4	85	103	55	94.0	
Female	75	105	150		128.1	

[1] All the terrapins in a pen seldom are found at one time. The decrease in size probably is due to missing one of the smallest animals the preceding year.

TABLE 26.—*Rate of growth of the brood of 1914*

When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Remarks
		Mm.	*Mm.*		*Mm.*	
May 24, 1915	351	25	48		32.9	Fed fresh fish.
Do	376	24	45		31.5	Fed salt fish first winter.
Aug. 25, 1915	284	27	67		42.2	Fed fresh fish.
Do	303	28	69		41.6	Fed salt fish first winter.
Do	100	49	69		54.2	Selected 100 best from preceding lots.
Sept. 20, 1916	97	58	93		70.3	
Oct. 11, 1917	88	63	115		81.6	
Oct. 3, 1918	91	75	126	1	93.2	Two males present in lot but they were not kept separate in measurements and therefore their size can not be shown.
Oct. 2, 1919	91	76	133	2	96.1	
Oct. 13, 1920	91	76	138	9	101.3	
Dec. 12, 1922	92	79	144	19	114.0	
Oct. 10, 1923	97	87	146	27	116.6	
Oct. 21, 1925	85	84	149	34	121.3	

TABLE 27.—*Rate of growth of the brood of 1915*

When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*			*Mm.*	*Mm.*		*Mm.*
Mar. 15, 1916	[1] 613	24	40		29.9	Oct. 15, 1918	435	35	112		60.3
Mar. 16, 1916	[2] 662	25	51		33.8	Oct. 8, 1919	395	38	122		65.6
Aug. 24, 1916	586	29	76		44.8	Oct. 8, 1920	338	41	134	2	69.4
Oct. 13, 1917	475	32	94		50.8	June 23, 1921	303	47	127	1	69.9

[1] This lot was fed on salted fish during the winter of 1915–16. After these measurements were taken it was discarded.
[2] This lot was fed on fresh fish during the winter of 1915–16. All subsequent measurements are based on this lot. It was discarded after the last measurements listed in the table were taken.

TABLE 28.—*Rate of growth of the brood of 1916*

When measured	Offspring of wild brood stock					Offspring of domestic stock				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
May 25, 1917	1,040	23	80		39.2	670	24	62		32.5
Oct. 4, 1918	[1] 120	47	104		70.6	[1] 81	47	83		63.2
Oct. 9, 1919	99	[2] 45	116		74.4	96	[2] 45	85		65.3
Oct. 8, 1920	99	[2] 42	123		75.5	95	47	92		66.8
Sept. 24, 1921	99	56	133	1	82.6	88	53	103		73.7
Sept. 13, 1922	103	69	136	4	91.4	92	69	120		85.2
Oct. 5, 1923	100	74	138	4	97.2	91	71	135	2	93.0
Sept. 12, 1924	100	77	139	6	101.9	95	73	[2] 130	2	95.5
Oct. 20, 1925	93	78	140	7	103.3	95	74	132	5	98.0
Oct. 1, 1927: [3]										
Male	18	81	102	33	89.3	22	78	101	33	90.7
Female	82	92	141		119.4	76	83	141		116.4

[1] This lot was selected at 1 year of age from the lot listed above.
[2] The apparent decrease in size probably is due to closer measurements or to the probability that the same terrapins were not measured each year, for all the animals in a pen often are not found.
[3] The measurements of the sexes were not definitely kept separate prior to this date.

TABLE 29.—*Rate of growth of the brood of 1917*

When measured	Close confinement					Wide range				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
May 19, 1919	100	50	84		60.1	100	46	72		52.5
Oct. 23, 1919	98	51	101		66.7	81	50	81		60.9
Oct. 5, 1920	[1] 50	58	109		74.8	[1] 63	57	96		70.6
Sept. 24, 1921	50	68	127	1	89.5	58	61	109		81.1
Sept. 13, 1922	55	77	135	3	97.8	51	81	121		96.3
Oct. 5, 1923	53	84	141	10	107.9	48	82	135	1	100.4
Sept. 11, 1924	50	86	141	15	112.1	44	83	139	1	101.7
Oct. 20, 1925	53	[2] 82	144	19	117.0	41	85	[2] 130	2	102.3
Sept. 30, 1926	50	91	152	32	123.8	39	85	147	13	118.0
Oct. 15, 1927	[3] 50	89	154	37	134.8	[4] 39	87	150	31	126.4

[1] Rats destroyed many of the animals in this lot. Others probably were not found when measurements were taken.
[2] The apparent decrease in size probably is brought about measuring different terrapins, as all the animals in any 1 pen seldom are found.
[3] This lot contained 10 males, but the measurements for them were not kept separate and can not be given.
[4] This lot contained 7 males, but the measurements for them were not kept separate and can not be given.

TABLE 30.—*Rate of growth of the offspring of the wild and domestic brood stock of the 1919 brood*

When measured	Offspring of wild brood stock					Offspring of domestic brood stock				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
May 11, 1920	[1] 73	30	55		38.2	[1] 85	23	48		35.7
Do	[2] 85	26	46		34.1	[2] 84	26	54		34.2
May 13, 1920	[3] 100	37	55		38.4	[4] 100	33	48		40.2
Sept. 30, 1921	54	36	71		51.8	90	41	82		62.0
Sept. 19, 1922	47	49	96		70.7	87	46	110		77.4
Oct. 10, 1923						81	53	117		87.6
Oct. 8, 1924	46	75	114		91.3	78	69	123		90.2
Oct. 27, 1925	44	78	123		96.0	78	75	132	4	95.3
Oct. 8, 1926	41	83	135		101.0	78	75	139	14	104.7
Sept. 28, 1927:										
Males						22	74	98	26	90.4
Females						52	87	144		119.3

[1] This lot, which originally consisted of 100 terrapins, was fed on oysters during the winter of 1919–20.
[2] This lot, which originally consisted of 100 terrapins, was fed on fresh fish during the winter of 1919–20.
[3] This lot was selected on May 13, 1920, from the 2 lots listed above, and it originally consisted of 100 terrapins, some of which were destroyed by rats. All subsequent measurements were based upon the surviving ones of this lot.
[4] This lot was selected from the 2 lots listed under the preceding date. All subsequent measurements were based upon the surviving ones of this lot.

TABLE 31.—*Rate of growth of hybrid terrapins of the brood of 1919*

When measured	Texas males and Carolina females					Carolina males and Texas females				
	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
May 11, 1920	[1] 48	25	52		35.6	[1] 96	26	47		33.4
Do	[2] 50	26	48		34.0	[2] 96	27	49		32.9
May 12, 1920	[3] 80	28	52		35.7	[3] 100	29	49		35.5
Sept. 24, 1921	[4] 54	33	90		63.0	[4] 30	43	93		58.3
Sept. 14, 1922	53	42	107		78.0	31	[5] 41	[5] 92		62.3
Oct. 10, 1923	54	55	120		86.1	31	65	119		83.1
Oct. 9, 1924	53	[5] 52	124		89.2	31	74	127	2	92.8
Oct. 22, 1925	49	61	135	3	95.5	30	[5] 72	130	1	94.2
Oct. 2, 1926	51	72	144	7	98.3	30	72	143	4	102.6
Sept. 28, 1927:										
Males	33	86	104	10	98.3	18	81	108	8	91.8
Females	19	81	148		125.3	13	92	150		127.0

[1] This lot was fed on oysters during the winter of 1919–20.
[2] This lot was fed on fish during the winter of 1919–20.
[3] This lot was selected on May 12, 1920, from the 2 lots listed under the preceding date. All subsequent measurements were based upon the surviving ones of this date.
[4] Many terrapins were destroyed by rats.
[5] The apparent decrease in size may be accounted for by closer measurements or by the fact that the same terrapins are not measured each year, as all the terrapins in a pen often are not found.

TABLE 32.—*Rate of growth of the Carolina terrapins of the brood of 1920*

When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*		*Mm.*	*Mm.*		*Mm.*
May 13, 1921	[1] 1,994	22	54		31.8					
June 1, 1921	[2] 200	32	47		38.5	[3] 50	33	45		37.5
Sept. 24, 1921	165	35	57		43.8	50	46	83		59.6
Sept. 14, 1922	163	35	73		50.3					
Oct. 10, 1923	144	40	87		61.3	39	68	105		83.2
Oct. 11, 1924	145	45	110		63.0	[4] 31	76	108		91.1
Oct. 22, 1925	122	52	111		75.7					
Oct. 1, 1926	121	56	126	1	84.7	26	76	130	4	108.0
Sept. 28, 1927:										
Males	23	72	97	2	84.0	25	98	138	6	116.9
Females	89	61	132		98.1					

[1] This lot contains all the winter-fed animals of the brood. The 2 lots listed under the next date were taken from this one.
[2] Offspring of domestic stock.
[3] Offspring of wild stock.
[4] 13 males, for which no measurements are available, were removed from this lot.

TABLE 33.—*Rate of growth of hybrids of the 1920 brood produced by crossing Carolina males with Texas females*

When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length	When measured	Number	Smallest	Largest	Females 125 mm. or more in length	Average length
		Mm.	*Mm.*		*Mm.*			*Mm.*	*Mm.*		*Mm.*
June 13, 1921	87	28	50		38.5	Oct. 20, 1925	63	66	121		96.1
Oct. 3, 1921	65	31	68		48.4	Sept. 30, 1926	60	82	135	9	105.1
Sept. 14, 1922	67	41	86		63.6	Oct. 1, 1927:					
Oct. 5, 1923	64	51	115		79.1	Males	40	85	109	10	94.4
Sept. 12, 1924	64	55	115		86.6	Females	20	108	146		128.2

TABLE 34.—*Rate of growth of the brood of 1921*

When measured	Number	Smallest	Largest	Average length	When measured	Number	Smallest	Largest	Average length
		Mm.	*Mm.*	*Mm.*			*Mm.*	*Mm.*	*Mm.*
May 18, 1922	2,101	25	50	31.8	Oct. 27, 1925	45	51	106	78.8
June 5, 1922	[1] 100	29	42	34.4	Oct. 6, 1926	41	79	120	86.0
Sept. 19, 1922	72	29	48	38.5	Oct. 21, 1927:				
Oct. 5, 1923	56	40	69	55.3	Males	2	86	92	89.5
Oct. 7, 1924	50	46	94	64.4	Females	31	93	124	108.3

[1] This lot was selected from the one listed under the preceding date.

TABLE 35.—*Rate of growth of the brood of 1922*

When measured	Offspring of domestic stock				Offspring of wild stock			
	Number	Smallest	Largest	Average length	Number	Smallest	Largest	Average length
		Mm.	*Mm.*	*Mm.*		*Mm.*	*Mm.*	*Mm.*
May 23, 1923	2,051	23	47	31.9	454	25	51	33.3
June 3, 1923	200	36	47	37.0	200	36	51	37.2
Oct. 24, 1924	[1] 130	36	70	43.1	[1] 142	36	72	47.5
Oct. 27, 1925	105	41	84	53.4	99	41	92	58.0
Oct. 7, 1926	94	42	91	62.3	93	44	95	65.2
Sept. 27, 1927	93	46	106	78.7	93	51	130	80.6

[1] This lot was selected from the one listed under the preceding date.

PERIOD OF ACTIVITY

The length of the period of activity of diamond-back terrapins, of course, varies from year to year according to temperatures. At Beaufort some of the animals begin to move about on warm days in March, but generally they do not become active and take food until about the latter part of April or early in May, and the period of activity may be said to end again sometime during October or, rarely, as late as early in November. They feed regularly only from about the latter part of May until early in October. On cool days they cease to feed and even mild days in midsummer cut down their capacity for food.

FOOD, FEEDING, AND COST OF FOOD

The food of terrapins in nature is reported to consist of small mollusks and crustaceans. In captivity, as already indicated, they readily take fish cut in pieces of suitable size, crabs, shucked oysters, and clams. At Beaufort, however, fish and some blue crabs chiefly are fed. Fiddler crabs enter the pens, and some small mollusks, too, are available. The animals appear to thrive on these foods.

The fish used during the summer are purchased directly from commercial fishermen, and they generally consist of menhaden and other unsalable fish or of small food fishes that would bring little on the market. Frequently quite a few blue crabs are included with the "scrap" fish. During the winter months, when only about 1½ pounds of food a day is used, small and cheap grades of fish are purchased from local fish dealers; or when oysters were fed they either were collected by the terrapin culturist or purchased in the shell and opened at the laboratory.

During 1927 the fish and crabs delivered by the fishermen were purchased at 2 cents per pound. During the winter, when the fish were bought from dealers, the price ranged from 6 to 7¼ cents per pound. The total cost of food for the calendar year 1927 was $236.52. With this amount, about 2,936 recently hatched young terrapins were fed during the winter and 3,707 animals of various ages (mostly adults) were fed during the summer. The cost of food for the young winter-fed animals for a seven-months period was 7½ mills per head. The cost for all the animals held in outdoor pens for the year 1927 averaged nearly 6 cents per head. It is evident, therefore, that the cost of food at Beaufort is not great.

For the small terrapins, a year or less of age, the fish are scaled, the large bones are removed, and then they are put through a food chopper. For larger terrapins, the fish and crabs together, as received from the fishermen, are put through a feed cutter of the type used by farmers, which cuts the food into pieces small enough to be managed by the terrapins. The food is thrown on the ground in a clean, solid place near the edge of the water. The animals emerge, take a piece of food, and generally return to the water to eat it. Care is exercised to supply sufficient food and not too much. Food placed on the ground at the edge of the water can be removed readily if it is not all consumed, for it is highly essential to prevent putrefaction, and less is wasted by the animals than if it were thrown into the water.

COPULATION, LAYING SEASON, AND INCUBATION PERIOD

Copulation seldom has been observed. Males frequently persist in following certain females, however, and it is supposed that this indicates a desire to copulate and that copulation probably follows. If that be true, copulation may take place at any time during the period of activity. This sex activity is greatest in the spring, very soon after the animals emerge from hibernation, and it is probable that that is the chief "mating" season.

The laying season begins in May, generally about the middle of the month, and it ends about the first of August. A female may lay only once during a season, or she may lay as many as four and, rarely, five times.

The earliest date of hatching that has been noticed at Beaufort was July 28, but generally hatching does not occur before the middle of August, and the last eggs hatch during the first half of October. The length of the incubation period, of course, varies somewhat with the prevailing temperatures, being shortened by high temperatures and lengthened by low ones. Using the earliest dates (generally around May 15) when laying was observed and the first dates (generally around August 15) when young terrapins emerged from the nests as a basis, the incubation period would appear to extend over about 90 days. Since newly hatched terrapins generally do not emerge from the nests immediately upon hatching, it may be assumed that the incubation period is somewhat short of 90 days.

SPACE REQUIREMENTS

It has been shown elsewhere (p. 53) that it seems practicable to confine as many as 100 recently hatched terrapins for winter feeding in a brooder house in a tank having a floor space of about 20 by 24 inches. To this statement there is little to add, except the caution that a high degree of cleanliness must be maintained. The tanks in which the animals were held at Beaufort under such crowded conditions were washed twice a day and scrubbed whenever it appeared necessary, and after each washing and scrubbing new and clean water was supplied. Care must be taken particularly to prevent the decay in the tanks of uneaten foods.

The extent of crowding that terrapins can stand in outdoor pens is not well known. None of the experiments performed to date indicate that the different degrees of crowding that have been tried were deleterious. Certainly, much depends upon cleanliness and the free exchange of water; that is, much greater crowding will be possible when the pens are fairly free of decaying organic matter and when the tides and conditions are such that an almost complete exchange of water takes place twice daily and clean water is brought by each flood tide. The greatest crowding of growing and fairly large terrapins among the experiments under way at Beaufort is 198 in a pen 5 feet wide and 36 feet long. The length of the pen probably has little significance as the animals stay in the water, or at least very close to it nearly all of the time. Therefore, only about one to three fourths, depending upon the stage of the tide, of this particular pen generally is occupied by the animals. The rate of growth of the animals in this pen compares favorably with other less crowded lots, and from the standpoint of survival this lot is ahead of all others grown in captivity.

In 1919, 100 animals of the 1917 brood were placed in a small pen measuring about 5 feet wide by 36 feet deep and 100 in a much larger pen, similarly situated, having a width of about 24 feet and a depth of about 36 feet. Owing to depredations by rats the numbers were greatly reduced. In 1927 only 50 animals were left in the small pen, and these (including 10 males) had an average length of about 5⅜ inches (134.8 millimeters), whereas only 39 were found (more animals probably were present, but they were difficult to find due to the large size of the pen) in the larger pen, which (including 7 males) had an average length of slightly over 5 inches (126.4 millimeters). If this experiment could be used as a criterion, "close range" would seem to be better than a wider one. The animals are sluggish, and it is not believed that a large pen is necessary for the purpose of providing space for exercise. The main consideration is the provision of sufficient room to furnish the necessary sanitation.

It seems reasonable to conclude from the experiments described and from the results obtained with several other lots that under the conditions existing at Beaufort certainly as many as 100 animals may be held and grown to maturity in pens having an area of 5 by 32 feet. Space requirements, as already suggested, undoubtedly would vary in different localities according to the cleanness of the water brought by flood tides and other local conditions.

SEX RATIO

The sexes of terrapins can not be distinguished from external characters until a length of 3 to 4 inches is attained. When this size is reached the males may be recognized by the much larger and heavier tail. There are other differences, such as the smaller head and the more wedge-shaped posterior outline of the carapace in the male, but the most evident character is the tail. Because it is impossible to distinguish the sexes in young animals from external characters, and because dissections of such animals have not been attempted, information concerning sex ratio is still quite incomplete. It may be stated, however, that the males are greatly in the minority among the total number of terrapins grown to maturity in captivity. This becomes evident from the fact that in 1927 among a total of 1,300 such animals in which the sexes could be distinguished positively there were only 242 males, thus giving a ratio of 1 male to 4.4 females. Omitting certain hybrid lots, in which the males are numerous, and using only pure stock of Carolina terrapins, the ratio becomes 1 male to 6.4 females.

Most of the lots from which the foregoing data were derived consist of animals selected (usually at about 1 year of age) from a year's brood (which usually consisted of a few hundred to a thousand or more individuals) because of the rapid growth they had made, while the rest were liberated. One lot was selected for the opposite reason, however; that is, the "runts" were retained; and still other lots were unselected. It is not evident from the results that the selections affected the sex ratio constantly in any one direction. The large variation in sex ratio among the small lots on hand suggests, however, that the element of chance selection as well as chance survival may have been important.

The extremes in sex ratio are represented in two lots of the brood of 1911 of Carolina terrapins, and in a lot of hybrid terrapins (Carolina males crossed with

Texas females) hatched in 1920. The two lots of the 1911 brood originally consisted of two groups of 100 each of unselected animals. When last counted (1927), 163 of these terrapins were found, all of them being females; nor has a male ever been noticed among these animals.

The lot of hybrid terrapins to which reference was made in the preceding paragraph originally consisted of 100 animals selected at 8 months of age. This lot, when last counted (1927), consisted of 60 terrapins, of which 40 were males. It appears to be of interest to note further that a somewhat similar abundance of males prevails among the only other two lots of hybrid terrapins (both hatched in 1919) on hand. One of these is the product of Texas males crossed with Carolina females, and it originally consisted of 80 unselected animals. When last counted (1927), 52 of these terrapins were found, and 33 of them were males. The other lot at first contained 100 selected animals, the offspring of Carolina males crossed with Texas females. This lot, due largely to depredations by rats when the terrapins were small, has been reduced to 31, and of these 18 are males. The greatest abundance of males in pure stock occurs in a selected lot originally consisting of 100 young, now (1927) reduced to 74, of Carolina terrapins hatched in 1919, in which there are 22 males. In all other lots of pure stock the males are in an even smaller minority.

These data would appear to indicate that cross-breeding Carolina and Texas terrapins tended to increase the proportionate number of males. However, the lots are too small to justify that conclusion, and until more information is obtained it may be assumed that the present results are a mere coincidence.

Table No. 36 shows in detail the sex ratio existing among the several lots of terrapins grown in captivity. The lots appear to be sufficiently large and numerous to justify the conclusion that a considerably larger number of females than males may be expected to reach maturity in terrapin farming. This is important from a practical viewpoint, as the females reach a relatively much larger size than males and have a correspondingly greater value on the market. As stated elsewhere, no definite information relative to the natural sex ratio in terrapins has been gained. A few lots of young animals are on hand, however, which may help to cast some light on this problem when they reach a sufficiently large size to admit of the recognition of the sexes.

If it were assumed that the usual 1 to 1 ratio prevails among young terrapins, then it would follow that the males simply fail to reach maturity. The selection of the larger and stronger animals at about 1 year of age, as was often done, does not appear to have resulted in constantly choosing females in preference to males. If it had, then it might be reasonable to expect the males to be in the majority among those terrapins that were chosen because they were small and undersized. This does not appear to be the case, however, for a lot of 100 terrapins of the 1912 brood was selected at 1 year of age as the very poorest and smallest among several hundred animals. When last counted (1927), 64 animals were found and among them were only 10 males. In unselected groups of Carolina terrapins the males, too, are greatly in the minority.

The supposition that the males failed to mature is complicated by the fact that the number of males present at maturity in some of the unselected lots as well as selected ones, added to the total number of animals that died (assuming that the loss consisted wholly of males), still would not make a sex ratio of 1 to 1.

TABLE 36.—*Sex ratio in several lots of diamond-back terrapins hatched and grown to maturity in confinement* [1]

Year of hatching	Number originally in lot	Number on hand, 1927 [2]		Ratio of males to females	Remarks
		Males	*Females*		
1910	171	13	116	1:8.9	All fed first winter, some the second winter; unselected.
1910	119	5	87	1:17.4	Hibernated each winter; unselected.
1911	100	0	78		Fed first three winters; unselected.
1911	100	0	73		Hibernated each winter; unselected.
1912	100	10	54	1:5.4	Some fed first winter, all fed the second winter. Selected at the age of 1 year, the smallest of the entire brood, consisting of 1,221 animals.
1912	100	17	64	1:3.8	Majority fed first winter, all fed the second winter. Selected at the age of 1 year, the largest from the entire brood, consisting of 1,221 animals.
1913	100	4	75	1:18.8	Fed first winter; selected at 1 year of age, the largest from lot consisting of 504 animals.
1914	100	2	83	1:41.5	Fed first winter; selected at age of 1 year, the largest from a lot consisting of 587 animals.
1916	200	40	158	1:4.0	Fed first winter; selected at age of 1 year, the largest from a lot consisting of 1,710 animals.
1917	200	17	73	1:4.3	Fed first winter; selected at 9 months of age, the largest from a brood consisting of 961 animals.
1919	100	22	52	1:2.4	Fed first winter; selected at 8 months of age, the largest from a lot composed of 169 animals.
1919	80	33	18	1:0.5	Hybrids (Texas males and Carolina females). Fed first winter; unselected. Number reduced through depredations by rats when the terrapins were small.
1919	100	13	18	1:1.4	Hybrids (Carolina males and Texas females). Fed first winter; selected at 8 months of age, the largest from a lot consisting of 192 terrapins. Original number much reduced through depredations by rats when the terrapins were small.
1920	200	23	89	1:3.9	Fed first winter; selected at 8 months of age, the largest from several hundred animals.
1920	87	40	20	1:0.5	Hybrids (Carolina males and Texas females). Fed first winter; unselected.
Total	1,857	239	1,058		Ratio for all lots combined, 1 male to 4.4 females.

[1] The animals are Carolina terrapins unless otherwise stated under remarks.

[2] The difference between the number originally in a lot and the number on hand in 1927 does not indicate the natural death rate that has occurred in each group. In a few instances several animals were taken away and used for other purposes; in a few cases some terrapins were lost in a storm; and in several lots rats killed some of the animals while small. Furthermore, the census varies from year to year; for it is extremely difficult to capture all of the animals at one time, because of their highly developed hiding propensities; and therefore the census for any one lot may vary from one to several from one year to the next, even though no deaths have occurred and no animals have been removed.

SUMMARY

The present series of experiments in diamond-back terrapin culture was started in 1909. Two subspecies (Chesapeake and Carolina) of terrapins are used in the experiments. Texas terrapins, too, were used at one time but have been discarded, except as represented in certain hybrid lots. Some of the experiments that have been undertaken have not been carried on long enough to yield results, and upon those no report is given. The discussion is confined to the experiments from which noteworthy results have been secured.

Egg production has fluctuated greatly from year to year within lots and within broods. The number of eggs produced by individual females of the same age is known to vary from 5 to 29 during a single season. Within a single lot, egg production has varied from 7.6 to 23.9 eggs per female. It is concluded that in general terrapin culture an average annual production of 12 eggs per female may be expected.

The degree of fertility of the eggs, too, has fluctuated greatly, for which often no good reasons can be given. In general, the highest percentage of fertility has resulted in the lots having the largest proportionate number of males, although exceptions to this rule are noted. Data are presented that would indicate that with

the proper sex ratio present, which appears to be about one male to five females, at least 90 per cent of the eggs laid should be fertile.

Great fluctuations in the death rate have taken place among the young animals, both among the ones that were kept warm and fed during the winter as well as among the hibernating lots. The cause of the deaths in the hibernating lots is not known, but in the winter-fed lots the mortality has been due principally to two causes, namely, a disease causing sores and to "soft shell." The disease causing sores, which may be of bacterial origin, was not equally severe from year to year, and it, more than anything else, has caused fluctuations in the death rate of winter-fed animals. Soft shell is associated with a failure to eat, causing general emaciation and gradually the softening of the shell, frequently, although not always, followed by death. Soft shell also causes many deaths among terrapins after they emerge from hibernation, and it results in more deaths than all other losses combined in both groups of animals.

The percentage of terrapins that were grown to maturity has been reduced materially in some of the lots on hand through depredations by rats while the animals were small, losses during storms, and apparently by escapes made by the terrapins because of their well-developed climbing propensities.

Evidence is produced that would tend to show that about 60.7 per cent of the animals hatched may be grown to maturity and that winter feeding increases the rate of survival.

Terrapins have an average length of about 27 millimeters at hatching. Young animals, when kept warm—that is, if placed in a brooder house—remain active during the winter, and the majority of them will begin to take food within a month or two after hatching. If the young are left out doors, they do not feed until they are 7 to 8 months old; that is, they go into hibernation soon after hatching or they remain in the nests in which they are hatched to hibernate, and they do not feed until the weather gets warm the following spring.

Generally about 1 year's growth was gained during their first winter by the recently hatched young when placed in the brooder house, in which the temperature was kept as far as possible at 80° F. or higher; that is, an average gain of growth (for all lots that had been fed the first winter) of 4.7 millimeters was made. The advantage in growth attained through winter feeding usually was retained and, furthermore, the winter-fed animals produced eggs a year earlier than the hibernating lots.

Winter feeding, aside from its advantages with respect to earlier maturity when animals are grown in captivity, has the advantage of carrying the animals through the critical stages of life at an earlier age. When terrapin culture is engaged in for the purpose of rebuilding or augmenting the supply in nature, the winter-fed animals apparently are able to take care of themselves and stand just as good a chance of survival at an age of about 8 months as the hibernating ones do a year later. The earlier liberation reduces the amount of care necessary and presumably hastens returns.

Some females reach a length of about 5½ inches and sexual maturity in 5 years; others require a much longer time to reach this size and stage in life. Evidence is produced that tends to show that some females never reach a length as great as 6 inches. Males rarely exceed a length of 4¾ inches. Data are presented that show

that in general terrapins grow rather rapidly during the first 5 or 6 years, followed by a much slower growth, and after an age of 8 to 10 years is attained growth is so slow that it is almost negligible.

The males in all broods of Carolina terrapins grown to maturity have been greatly in the minority. This disproportionate sex ratio has existed in unselected lots as well as in selected ones. A ratio of 1 male to 6.4 females exists among the Carolina terrapins grown in captivity. In certain hybrid lots (crosses between Carolina and Texas terrapins) the males are much more numerous. Since the lots are small ones, this greater proportion of males may have no significance. If the usual 1-to-1 sex ratio exists in young terrapins (which has not been determined), then it apparently would have to be assumed that the males are less resistant to life in captivity than the females, and they simply fail to reach maturity. This supposition does not appear to be tenable, however, because the number of deaths in some of the lots was too few, even if males only had died, to make a ratio of 1 to 1.

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REVIEW OF THE WEAKFISHES (CYNOSCION) OF THE ATLANTIC AND GULF COASTS OF THE UNITED STATES, WITH A DESCRIPTION OF A NEW SPECIES [1]

By ISAAC GINSBURG

Assistant Aquatic Biologist, U. S. Bureau of Fisheries

The relation of the sand squeteague or, as it is locally called in Texas, sand trout of the Gulf coast to the gray squeteague of the Atlantic coast has been a perplexing problem. Welsh and Breder, who were the first authors of record to examine critically a large series of specimens and who recognized but a single species of sand trout from the Gulf coast, which they identified with *Cynoscion nothus*, state in regard to their species as follows:

> Examination of a large series of specimens taken by the Fisheries schooner *Grampus* in Gulf waters indicates that the species is very close to *Cynoscion regalis*, and that its claim to specific rank is at least doubtful. Although an apparently well-marked variety, further study may show complete intergradation of characters with the latter species. R. J. Coles (1916)[2] considers it simply a color variation of *C. regalis*. (Bulletin, U. S. Bureau of Fisheries, Vol. XXXIX, 1923–1924, p. 169.)

Commercially, the gray trout is a very important species in the fisheries of the Atlantic coast from Cape Cod to the coast of North Carolina. In any study of its migrations and localized races it becomes evident that it is important, first of all, to determine definitely its interrelationship with closely related species. It is especially important to know the exact morphological limits of the species in determining such problems as the age of the fish or its rate of growth. In general, it is axiomatic that in a study of the life history of any species all conclusions must be based on an examination of individuals of the same species, but this has not been the universal rule in the case of the squeteagues. Workers with these fishes, including myself, have not always properly separated their material and frequently have based their identifications on geographical lines. That this is true becomes evident from a study of the published records of these fishes as well as some of the material on which the records are based, after one becomes familiar with the real specific characters, as outlined below. Hitherto young individuals, especially, have been confused because they are almost inseparable in general appearance. The present study was undertaken for the purpose of finding, if possible, usable characters by which the individual fishes may be distinguished and recognized at all stages of growth.

The status of the species of Cynoscion on the Atlantic and Gulf coasts of the United States, as they are generally understood at the present time, may be reviewed and summarized as follows: First of all, we have the spotted squeteague, *Cynoscion nebulosus*. This species is fairly common on the Atlantic and Gulf coasts, and because of its distinctive color and scaleless dorsal and anal fins it is easily recognized and distinguished from the paler weakfishes. It is now generally agreed that there is but one species of spotted weakfish common to the Atlantic and Gulf coasts. This species is not considered in the present paper.

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[1] Submitted for publication Apr. 22, 1929.

[2] Russell J. Coles: Is *Cynoscion nothus* an abnormal *regalis*? Copeia, No. 30, Apr. 24, 1916, pp. 30–31. New York.

The gray weakfish or, as it is commonly called in more southern localities, the gray trout (*Cynoscion regalis*) is the common commercial fish of the Atlantic coast. The individuals comprising the commercial catch, or the vast majority of them, seem to belong to one species; at least now they are generally so regarded. As to the geographic distribution of this species, it is significant that authors generally have failed to record it from the Gulf coast, especially those who reported on extensive collections from that coast. Jordan and Eigenmann (Report, U. S. Fish Commission, 1886, p. 367) record it from Mobile based on material (the number of specimens not stated) in the Museum of Comparative Zoology at Harvard University. This is the only direct record of *regalis* from the Gulf that is known to me. In the literature Cuvier and Valenciennes generally are quoted as authority for including the Gulf coast in the range of *regalis*, but the statement on which this supposed record is based is as follows (Histoire Naturelle des Poissons, Tome 5, quarto ed., 1830, p. 53): "Les colons francais de la Nouvelle-Orleâns le possèdent aussi, et lui ont transféré le nom de *truite*, à cause de ses taches." This statement obviously refers to the spotted weakfish, since this is the only species of Cynoscion on the Gulf coast having well-defined spots.

A third form that is at present recognized is *Cynoscion nothus*. This was described originally from the coast of South Carolina and has since been recorded from Chesapeake Bay to the southwestern coast of Texas. There is difference of opinion as to the status of this species. Welsh and Breder, as quoted above, doubt the real distinctiveness of this form from *regalis*. On the other hand, Hildebrand and Schroeder (Bulletin, U. S. Bureau of Fisheries, Vol. XLIII, Pt. I, p. 300), who had two specimens of this species from Chesapeake Bay, state: "* * * the differences between a true *nothus*, such as we believe to have in hand now, and a *regalis* are so evident and so numerous * * *." Jordan and Gilbert (Proceedings, U. S. National Museum, Vol. V, 1882, p. 607) are the only authors known to me who record this species as being common on the Atlantic coast—namely, at Charleston, S. C. Incidentally, it may be stated that the description of the species given by these authors is probably the best extant, because it is evidently based on abundant material comprising specimens of this species only and not a mixture of individuals of different species. As to the occurrence of this form on the Gulf coast, nearly all authors who have worked over the fishes from that coast, especially those who have studied the fisheries and hence have dealt with masses of individuals, have referred the pale weakfish of the Gulf to *nothus*.

Finally, a fourth species has been described under the name of *thalassinus*. This species was first described by Holbrook (Ichthyology of South Carolina, 1855, p. 132, pl. 18, fig. 2) from a "few specimens" taken off the coast of South Carolina. Gunther (Catalogue of Fishes of the British Museum, vol. 2, 1860, p. 308), who had a single specimen of the pale weakfish from the Gulf coast, doubtfully referred it to *thalassinus*. Jordan and Eigenmann (op. cit.) have picked out three specimens from those studied by them—two from the Gulf and one from the Atlantic coast—and referred them to *thalassinus*. These authors state: "As *C. regalis* is subject to considerable variation, we have regarded *C. thalassinus* as an extreme form or variety rather than a distinct species. It may, perhaps, be found to inhabit a different depth of water than that which the common weakfish frequents." Jordan and Gilbert (Bulletin, U. S. National Museum, No. 16, 1882, p. 582) call it "a doubtful species." Welsh and Breder (op. cit., p. 148) state that "*Cynoscion thalassinus*

(Holbrook), which has not been recognized since the describer's time, seems to be merely nominal, as the description is close to *C. regalis* and *C. nothus*."

Briefly, then, the consensus of opinion at the present time may be stated as follows: Omitting the spotted squeteague, there are two species of squeteagues common enough to enter into the commercial catch; one, the gray squeteague (*Cynoscion regalis*), is the common market fish of the Atlantic coast, while the other, the bastard trout or sand trout (*Cynoscion nothus*), is the common market fish of the Gulf coast. *C. regalis* does not occur or is very rare on the Gulf coast, and *C. nothus* usually is taken rather sparingly on the Atlantic coast. *C. thalassinus* is a very doubtful species. I had these ideas in mind when I began the study of the sand trout of the Gulf. It soon became evident, however, that such ideas do not fit the actual facts, and a study of considerable available material was undertaken in order to throw more light, if possible, on the subject.

The present study has shown that instead of one there are two very distinct and easily separable species of sand trout on the Gulf coast. Both are common, although the relative abundance of the two must be left for future determination. One of these species is smaller than the other and, so far as the material at hand discloses, apparently does not enter to any great extent into the commercial catch; the other species is the common market fish. This larger and common species is not *nothus*. It is very close to *regalis*, but evidently is sufficiently distinct to require a separate designation and is here named *Cynoscion arenarius*. The name *thalassinus* is definitely based on specimens from the Atlantic coast and is not applicable to this species, which is confined to the Gulf coast.

The smaller Gulf species evidently is the same as that described by Holbrook under the name of *Otolithus nothus* and is here recognized under that name. Many specimens of this species from both the Atlantic and Gulf coast have been examined. Some of this material has been previously identified by me or by other workers either as *nothus* or *regalis*, depending on whether it came from the Gulf or the Atlantic coast, respectively. This is easily explained by the fact that nearly all of the material consists of small specimens of less than 7 inches, and when of that size the appearance of the fish is such that the species can not be distinguished by a mere visual comparison, even when such comparison is made by an experienced ichthyologist. However, when the distinguishing characters outlined below are examined no trouble will be experienced in identifying even the smallest specimens. When identification is thus definitely made, our material shows that *Cynoscion nothus* is really more common on the Atlantic coast, from North Carolina southward, than most of the discussions in current literature would seem to indicate.

The present study has failed to confirm the distinctness of the form that has been named *thalassinus*. Of the many specimens of gray trout examined from Chesapeake Bay, from the coasts of North and South Carolina, and from the east coast of Florida, I have failed to distinguish more than one species and am therefore forced to the conclusion that *thalassinus* is untenable. It was evidently based on some slender individuals of *regalis*, which manifestly show considerable variation in that character. The coloration shown by Holbrook is essentially that of *regalis*. The number of fin rays is used by the author as one of the chief distinguishing marks, but his counts are obviously unreliable; as, for instance, when he states that *regalis* has only 9 dorsal spines, whereas it nearly always has 10. Besides this, the number of soft dorsal rays given in the original description falls within the range of variation of

regalis, as noted below. The other characters given by him are apparently of no significance.

Instead of being hard to distinguish, as has been asserted, *Cynoscion nothus* is, in fact, readily separable. The present extensive study has revealed three striking characters that prove conclusively that this species is distinct, and by means of which a single individual may be identified readily; namely, (1) the number of vertebræ, (2) the correlation of the numbers of soft dorsal and anal rays, and (3) the absolute number of anal rays.

Counting the vertebræ of many individuals has shown that their number furnishes a valuable and positive character for differentiating this species from the other two. In the specimens of *Cynoscion nothus* counted there were always 27 vertebræ, except in one, which had 26. This was a small specimen from off the coast of North Carolina. Altogether 114 specimens of this species from the Gulf and Atlantic coasts were counted. *Cynoscion regalis* and *C. arenarius* invariably were found to have 25 vertebræ. Fifty-five specimens of these two forms were counted and recorded. The counts were made after the mass of muscles had been removed from one side. The first vertebra, which articulates with the skull and has a different shape than the succeeding vertebræ, and also the hypural were included in the count.

A study of the correlation of the numbers of dorsal and anal soft rays is what first led me to suspect that two distinct species were being confused under the name sand trout on the Texas coast. Table 1 shows this correlation in specimens from various localities on the Gulf coast. A mere glance at the table is sufficient to show that we are dealing here with two distinct forms, one having a shorter anal in combination with a longer dorsal than the other. Table 2 shows the same correlation for specimens from various localities on the Atlantic coast. Those specimens having the short anal in conjunction with a long dorsal also have 27 vertebræ and consequently are *Cynoscion nothus*. Comparing Tables 1 and 2 for *Cynoscion nothus* it may be seen that there is a tendency to an increase in the number of fin rays on the Atlantic coast. However, an increase in the number of rays in northern localities is a common phenomenon occurring among fishes having a wide latitudinal distribution. It may be noted that the increase occurs both in the anal as well as the dorsal, and the differences are not marked enough to be of specific significance.

For practical purposes merely counting the anal rays is sufficient to determine *nothus*. From an examination of Table 1 it will be seen that there is virtually a break in the series of 217 specimens enumerated, as far as the number of anal rays is concerned, except for 12 individuals. Every one of these 12 specimens was dissected and found to have 25 vertebræ, which placed them definitely with *arenarius*. The number of specimens examined is sufficient, for practical purposes, to enable us to make the statement that in Gulf waters *nothus* has 8 or 9 soft anal rays, while *arenarius* has 10 to 12. Similarly, Table 2 shows that for Atlantic coast fish there is a virtual break in the number of anal rays even more pronounced than in Gulf specimens, there being only 5 of 259 Atlantic fish examined that may be said to be intermediate. Of these 5 specimens 4 were found to have 27 vertebræ, which places them unquestionaly with *nothus*, and 1 had 26. This is the only individual of all those examined for vertebræ (169 in all) that had 26, all the others having either 25 or 27. It is a small specimen, having a standard length of 49 millimeters, taken at Beaufort, N. C., on September 29, 1926. Since on the same trip many others of similar size and presumably in company with it were taken, which

unquestionably were *nothus*, it may safely be assumed that this single individual is a *nothus* showing a rare individual variation. On the basis of the material examined, which was manifestly sufficient for all practical purposes in so far as distinguishing species is concerned, it may be stated that on the Atlantic coast *nothus* has 8 to 10 anal rays and *regalis* 11 to 13.

TABLE 1.—*Correlation of the number of articulate rays of the dorsal and anal fins of Cynoscion arenarius and C. nothus from the coast of the Gulf of Mexico*

[The first short ray of the soft dorsal, which is about one-fourth as long as the anterior fully developed rays and apparently remains unjointed even in the largest specimens, has not been included in the count. The second ray, which is about one-half to two-thirds as long as the anterior fully developed rays and becomes more or less jointed, has been included. The last two rays of both the dorsal and the anal, which apparently are joined at their base, have been counted as one. All specimens having 10 anal rays have been checked by the vertebral count and found to belong to *arenarius*. The numbers in the body of the table represent frequencies]

Anal rays	Dorsal rays							
	24	25	26	27	28	29	30	31
Cynoscion nothus:								
8				5	6	3		
9				11	41	28	3	1
C. arenarius:								
10		9	3					
11	2	22	49	18	1			
12		4	7	4				

TABLE 2.—*Correlation of the number of dorsal and anal articulate rays of Cynoscion regalis and C. nothus from the Atlantic coast. (All specimens having 10 anal rays belong to nothus, as shown by the vertebral count)*

Anal rays	Dorsal rays							
	24	25	26	27	28	29	30	31
Cynoscion nothus:								
8				1	3			
9					19	34	5	3
10				1	1	2	1	
C. regalis:								
11		5	14	21	16	1		
12			12	62	44	9		
13				1	3	1		

It is not deemed necessary for the purpose of the present study to expend more time in working out in detail other structural marks that differentiate *nothus*, since the three characters outlined above convincingly prove its distinctness and constitute usable marks for identifying individual fish. Indeed, according to the standards that some authors use in creating genera, the single character of the vertebral count may be considered to be of generic importance.

Having thus definitely delimited and separated out the smaller *Cynoscion nothus*, there are left the two larger common commercial species—of the Atlantic and Gulf coasts, respectively—and the next matter to settle is the relation between the two. The common commercial fish of the Gulf coast is not *nothus*, as has been generally supposed; it is either *regalis* or something else. In considering the differences between the Gulf fish and the *regalis* of the Atlantic coast it is well to take note of the fact that nearly all previous authors have regarded the common sand trout of the Gulf as different from the gray trout of the Atlantic. The fact that it was generally referred to *nothus* is beside the question. The important fact to remember is that the commercial Gulf fish is apparently of such a different appearance from the Atlantic fish that it was

generally referred to a different species, even by investigators who dealt with the large numbers of individuals handled by fishermen. The Atlantic and Gulf forms, then, apparently are separable when taken in bulk, but when we consider each character separately the matter is not so simple because usually there is considerable intergradation. However, when all the characters are considered together it becomes evident that the two fish are sufficiently different to be regarded as distinct species. The more striking differentiating characters are as follows:

Color.—Apparently color was the chief character on which the distinction rested heretofore. The difference in adult fish is quite striking. The Atlantic coast fish usually has small spots arranged in rather indefinite and irregular streaks, while

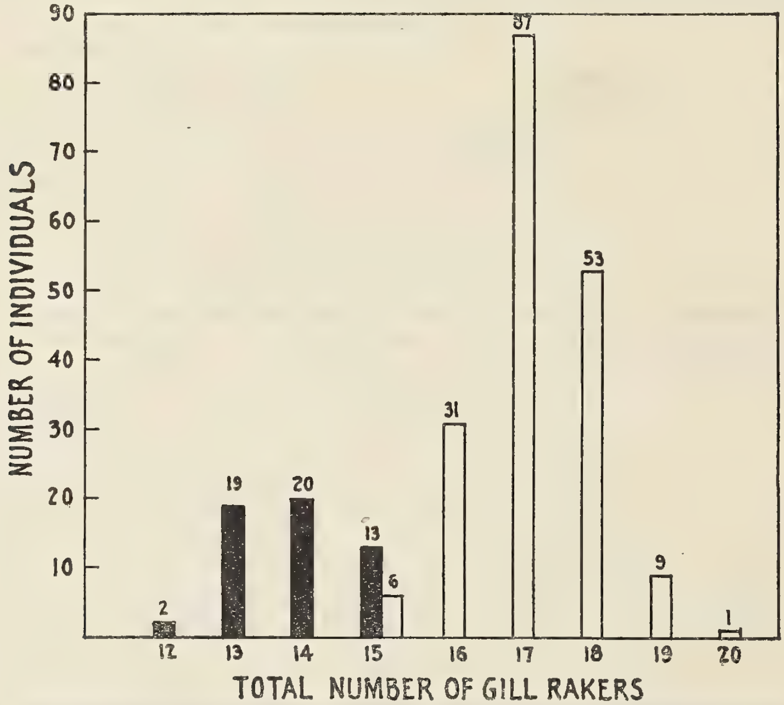

FIGURE 1.—Frequency distribution of the total number of gill rakers on the first gill arch of *Cynoscion arenarius* and *C. regalis*. The solid columns represent specimens from the Gulf of Mexico (*arenarius*) and the blank columns species from the Atlantic coast (*regalis*), in this as well as in the subsequent figures. The numbers at the top of the columns represent the actual number of specimens studied

the Gulf fish is usually pale. There is considerable variation in color. Occasionally there are Atlantic specimens that have the typical coloration faintly developed, while in some Gulf fish there may be faint development of pigmentation. However, taken as a whole, the adults of these two species may be separated nearly always by color alone, especially when in fresh condition. The young of both species are pale and hence can not be separated by color.

Form of the caudal fin.—As in many other sciænids, the caudal fin of the young of Cynoscion is very pointed, the middle rays being considerably prolonged. As the fish grow older the decided prolongation of the middle rays diminishes and the caudal fin becomes somewhat double concave. In *regalis* the transformation of the caudal fin is carried farther, and it becomes distinctly emarginate in large individuals. As may be expected in a case of this kind, there is considerable individual difference

in the size at which this change takes place. An examination of a number of *regalis* from Chesapeake Bay showed that the change to an emarginate condition takes place when the fish reaches a total length between 250 and 300 millimeters. All those below 250 millimeters have the middle rays of the caudal longest, in all those over 300 it is distinctly emarginate, while in those between these lengths both conditions may be found, and some of them have a caudal fin that can best be described as truncate. In *arenarius*, on the other hand, the middle rays of the fin are longest, even in specimens over 300 millimeters long. It may be remarked that the fins of these fishes are rather brittle, and in preserved material they are more or less frayed. This probably explains why this character is not mentioned more often in discussions of the differences between the two forms. However, judging from the condition of our specimens, it is apparent that the difference in the form of the caudal is substantially as described.

Number of gill rakers.—This character has been mentioned by previous writers as differentiating the Gulf and Atlantic forms, and the present study has shown it to be usable, but there is considerable overlapping. The modal number for *regalis* in specimens of over 70 millimeters, standard length, is 5+12, while in *arenarius* it is 3+10 or 4+10. In the study of this character the size of the fish must be taken into consideration, since it has been found that the number varies with the size, especially in *arenarius*. In the young fish the gill rakers are comparatively longer and more slender. As the fish grow older they become shorter and stouter, and the foremost one on the lower limb of the first arch and one or two uppermost ones on the upper limb tend to become absorbed and disappear. Moreover, this disappearance is more marked in *arenarius*, and consequently when larger specimens are compared the difference is more pronounced.

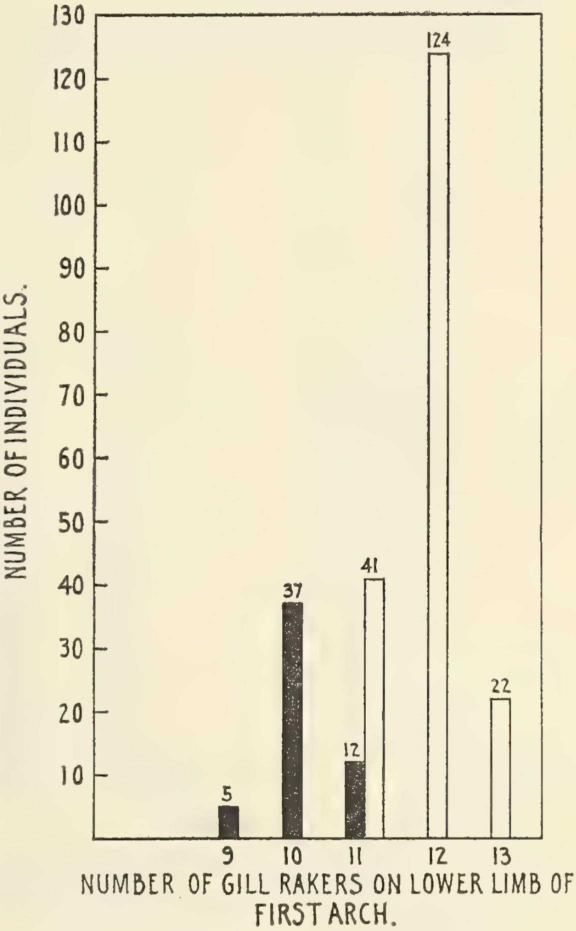

FIGURE 2.—Frequency distribution of the number of gill rakers on the lower limb of the first arch of *Cynoscion arenarius* and *C. regalis*. The one gill raker that stands at the angle of the arch and has one root on the lower limb and one on the upper limb has been included uniformly in this count

For the purposes of the present study all specimens have been divided into two groups, those of 70 millimeters or less and those over 70 millimeters standard length, and like groups have been compared. It might have been desirable to make a finer division of groups, but there was not enough material of all sizes in both forms. However, this division seems sufficient to bring out the essential facts. Figures 1 and

2 are graphic representations of the frequency distribution of the gill rakers in the group of larger specimens. In 69 smaller specimens of *arenarius* of 30 to 60 millimeters the mode for the total number of gill rakers falls at 15, with the class 16 a very close second. Comparing these smaller specimens of *arenarius* with the larger *regalis*, it may be seen that the modes are even then distinct, although the overlapping is quite considerable. I do not have a sufficient number of smaller *regalis* to establish the frequency distribution, but from the few specimens counted it seems evident that the difference between the larger and smaller members of this species is not so marked as it is in *arenarius*.

A precaution to be taken when the number of gill rakers is used as a distinguishing character may be mentioned. As may be conjectured, it is sometimes difficult to

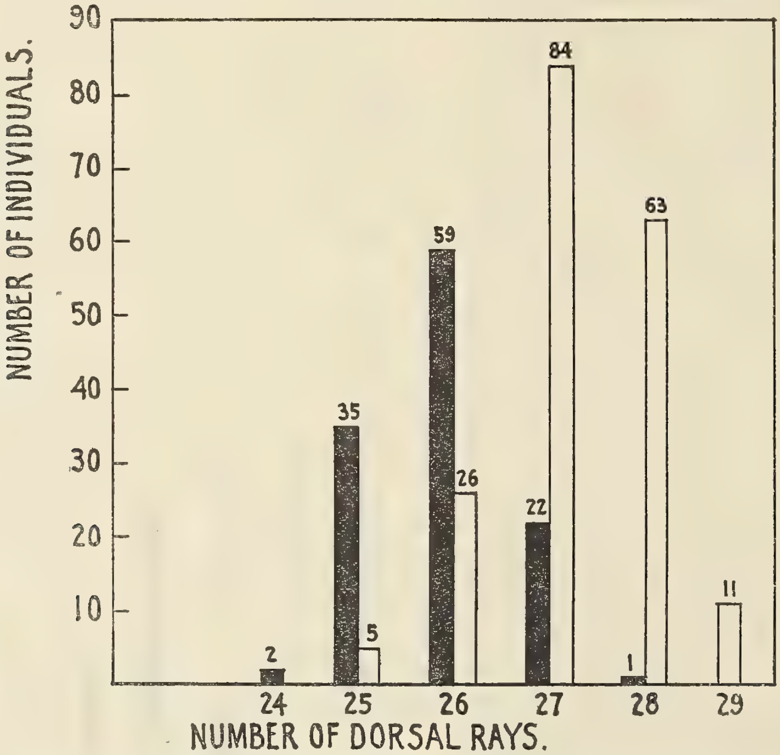

FIGURE 3.—Frequency distribution of soft articulate dorsal fin rays of *Cynoscion arenarius* and *C. regalis*. The first short ray, which remains unjointed in the largest specimens, was not included in the count, and the last two rays, which are apparently united at their base, have been counted as one

decide as to what constitutes a gill raker and what is a mere tubercle at each end of the gill arch. It is hard to describe in so many words where a line may be drawn. The number counted will vary somewhat with the observer, but when the same investigator makes the counts in both species the numbers are comparable. In the present study all gill rakers were included that were big enough to be manipulated with a dissecting needle, or about 1 millimeter long as a rough estimate. If the gill rakers on the lower limb only are counted, the number of doubtful cases will be surprisingly small. When the total number of gill rakers is enumerated, the divergence in the two species is emphasized because there is usually a difference of one or two gill rakers also on the upper limb. However, there is greater chance for error

due to the personal equation of the observer, because it is harder to draw a line between gill rakers and tubercles at the uppermost part of the gill arch. In the present study, therefore, the number of gill rakers on the lower limb (fig. 2) and also the total number (fig. 1) have been enumerated separately, the first because of the greater accuracy possible and the second because of the greater divergence shown.

Number of fin rays.—Figures 3 and 4 represent the number of articulate fin rays in the dorsal and anal, respectively. It may be seen at a glance that while there is considerable overlapping, each form shows a strongly marked mode. Furthermore, the mode is markedly conspicuous in both characters. While, because of the large number of overlapping individuals, these characters by themselves do not prove the distinctness of the two species very convincingly, yet they furnish additional proof when considered in conjunction with the other characters. The advantage in the use of the fin rays lies in that their numbers can be determined accurately in terms of exact figures and are not subject to variation with the personal idiosyncracies of the observer or with the size of the fish.

Using the following standard formulæ:

$$\text{Standard deviation} = \sigma = \sqrt{\frac{\Sigma f x^2}{n}}$$

probable error of arithmetic mean $= E = \pm 0.6745 \frac{\sigma}{\sqrt{n}}$

and probable difference $= \sqrt{E_1^2 + E_2^2}$

some statistical constants have been worked out for the numerically variable characters of gill raker and fin-ray counts. These constants are shown in Table 3. The numerical values of the ratios of the actual differences of the arithmetic means to the probable differences are high in every case and serve to emphasize the distinctness of the two species.

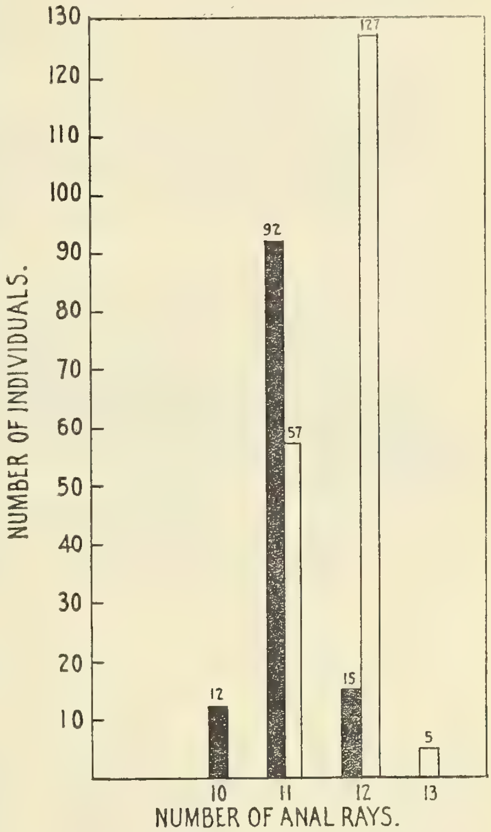

FIGURE 4.—Frequency distribution of soft articulate anal fin rays of *Cynoscion arenarius* and *C. regalis*. The last two rays, which apparently are united at the base, have been counted as one.

TABLE 3.—*Some statistical constants showing the divergence between Cynoscion regalis from the Atlantic coast and C. arenarius from the Gulf coast*

	Gill rakers, entire first arch		Gill rakers, lower limb only		Dorsal rays		Anal rays	
	C. regalis	C. arenarius	C. regalis	C. arenarius	C. regalis	C. arenarius	C. regalis	C. arenarius
Mean	17.26	13.81	11.90	10.13	27.26	25.87	11.72	11.03
Standard deviation of mean	.894	.829	.570	.546	.862	.751	.502	.476
Probable error of mean	.044	.076	.028	.050	.042	.046	.025	.029
Probable difference of means	.088		.057		.063		.038	
Actual difference	3.45		1.77		1.39		.69	
Actual difference divided by probable difference	39		31		22		18	

Proportional measurements.—In addition to the characters discussed above there are also some significant proportional measurements. A number of measurements expressed as percentages of the standard length are given in Table 4. Of course, the measurements are too few to warrant drawing any general conclusions. They were intended merely as a test to show whether such characters will separate the two forms more convincingly. Of the various measurements taken it may be seen that those that show the greatest divergence are the length of the maxillary, the length of the snout, and the depth of the caudal peduncle. However, a close examination of the figures seems to show that if a long series of measurements be taken, most likely the results will not be more convincing than are the characters already mentioned. They will probably only duplicate the previous results and emphasize the fundamental differences between the two forms while at the same time showing their close relationship. It is, therefore, not deemed necessary for our purpose to undertake the extra labor of a long series of measurements. The magnitude of the test is also increased by the fact that the proportional measurements vary greatly with the size of the fish and hence are not comparable when taken from fish of widely different sizes.

Table 4 shows that the length of the snout and of the maxillary and the depth of the caudal peduncle vary in the two species in different directions—in *regalis* the snout and maxillary are shorter while the peduncle is deeper than in *arenarius*. Hence, the divergence in the two species may be shown more clearly when these measurements are compared. This is done in Table 5, the figures representing the number of times the depth of the caudal peduncle goes into the length of the snout and the maxillary, respectively.

TABLE 4.—*Some proportional measurements of Cynoscion regalis and C. arenarius*

[The numbers represent percentages of the standard length; that is, the distance from the tip of the snout to the base of the caudal]

Standard length	Snout	Maxillary	Least depth of caudal peduncle	End of insertion of dorsal to base of caudal on mid line	Vent to end of insertion of anal	Head	Depth	Eye
Cynoscion regalis:								
275	8.25	13.31	8.84	13.71	14.22	30.76	23.64	5.13
247	8.14	13.52	8.71	12.35	14.94	30.04	24.66	5.26
236	8.09	14.07	9.36	13.77	15.21	30.59	23.31	5.89
208	9.04	14.86	9.47	13.56	14.42	32.46	27.98	6.59
200	7.75	13.85	9.30	13.35	14.65	30.70	24.60	6.35
197	8.32	13.96	9.34	12.28	16.55	31.22	23.60	6.40
178	8.99	14.66	9.38	11.69	14.61	32.64	24.04	6.69
167	8.62	14.19	9.76	12.40	16.53	32.22	25.39	6.77
162	7.90	13.70	9.88	13.83	16.54	30.93	25.08	7.00
102	8.92	15.29	9.22	12.66	18.18	34.61	27.16	8.53
C. arenarius:								
268	9.70	14.55	8.43	12.31	15.41	31.23	25.00	5.11
242	8.88	14.50	8.68	12.56	14.79	31.49	25.08	5.37
228	9.00	14.43	8.46	14.17	14.03	31.27	24.30	5.61
213	9.15	15.12	8.31	13.80	12.63	32.30	25.82	5.87
203	8.97	15.00	8.33	13.35	14.53	32.02	23.30	5.86
184	9.18	14.95	8.59	13.48	13.91	32.60	23.70	6.30
178	9.44	14.78	8.31	13.60	15.17	32.58	24.49	6.40
173	9.31	14.80	9.13	12.83	16.18	32.89	26.82	6.53
169	9.35	14.50	9.23	13.07	14.79	31.36	27.22	6.45
110	8.91	15.00	8.36	12.45	15.64	33.82	24.18	7.91

TABLE 5.—*Relation between the least depth of the caudal peduncle and the lengths of the snout and the maxillary* [1]

Species	Standard length	Least depth of caudal peduncle in snout	Least depth of caudal peduncle in maxillary	Species	Standard length	Least depth of caudal peduncle in snout	Least depth of caudal peduncle in maxillary
Cynoscion regalis	275	0.93	1.51	C. arenarius	268	1.15	1.73
	247	.93	1.55		242	1.02	1.67
	236	.86	1.50		228	1.06	1.70
	208	.95	1.57		213	1.10	1.82
	200	.83	1.49		203	1.08	1.80
	197	.89	1.49		184	1.07	1.74
	178	.96	1.56		178	1.14	1.78
	167	.88	1.45		173	1.02	1.62
	162	.80	1.39		169	1.01	1.57
	102	.97	1.66		110	1.07	1.79

[1] The figures represent the number of times the former is contained in the latter, respectively. Note that in the few specimens measured, which were taken at random except that specimens of approximately like size were taken for the purpose of comparison, there are no overlapping individuals for one ratio and a significant divergence for the other.

The data and conclusions presented above may now be summarized in the conventional form used in descriptive works.

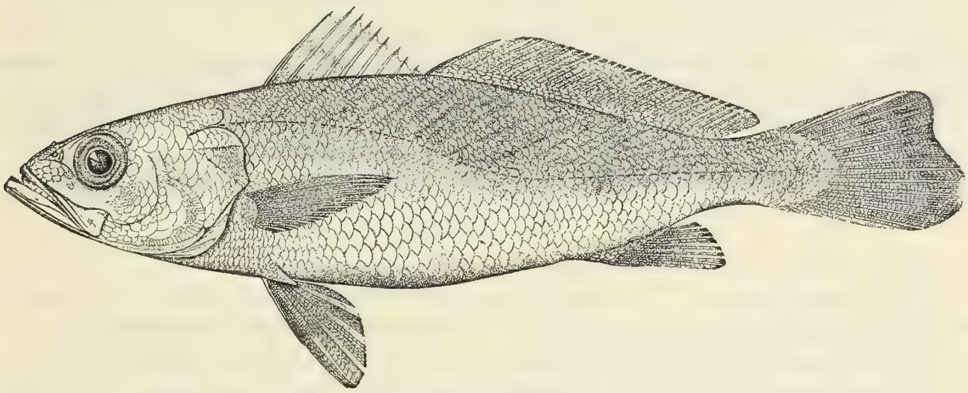

FIGURE 5.—*Cynoscion nothus* (Holbrook). Silver squeteague. Drawn by Louella E. Cable from a specimen taken off North Carolina

Cynoscion nothus (Holbrook)

Common name.—Silver squeteague.

Other common names.—Bastard trout (Chespeake Bay and coasts of North and South Carolina); sand trout (Texas coast, where it is not distinguished from *Cynoscion arenarius*).

Otolithus nothus Holbrook, Ichthyology of South Carolina, 1855, p. 134, pl. 19, fig. 1. (Type locality, coast of South Carolina.)

Cynoscion nothus Jordan and Gilbert, Proc., U. S. Nat. Mus., vol. 5, 1882, p. 607.

Cynoscion nothus Welsh and Breder (in part), Bull., U. S. Bureau of Fisheries, Vol. XXXIX, 1924, p. 169.

Cynoscion nothus Hildebrand and Schroeder, loc. cit., Vol. XLIII, 1928, Pt. I, p. 299.

Diagnosis.—Vertebræ nearly always 27 (113),[3] rarely 26 (1). Anal soft rays predominantly 9 (145), sometimes 8 (18), and infrequently 10 (5) in specimens from the Atlantic coast. Total number of gill rakers on the first arch in individuals of

[3] The number in parentheses refers to the actual number of specimens, on an examination of which the statement is based.

30 to 130 millimeters, enumerated together, have a mode of 13 (87), frequently 12 (33) or 14 (28), rarely 15 (3). Most common number of gill rakers on the first arch 3 + 10. There is somewhat of a tendency to a decrease in the number of gill rakers as the fish increases in size, but the mode remains the same in the smaller and larger specimens examined (30 to 130 millimeters standard length), the decrease not being as pronounced as in the following species. Snout rather short, shorter than the least depth of caudal peduncle. Caudal peduncle short, the length of the rather short maxillary greater than the distance from posterior end of insertion of dorsal to base of caudal on mid line. Eye conspicuously larger than in the two other species. Dorsal rather long, the usual number of soft rays 28 (71) or 29 (67), frequently 27 (18), less frequently 30 (9), rarely 31 (4); the number of rays increasing in more northern latitudes, the mode being at 28 in Gulf specimens, in those from Fernandina and Cape Canaveral, Fla., the numbers 28 and 29 are about equally distributed, while in North Carolina specimens the mode falls at 29. Color pale, without conspicuous pigmentation, the upper part usually straw or walnut, the lower part lighter silvery; sometimes an indication of irregular rows of faint spots. Small individuals, up to about 85 millimeters standard length, have the upper part more or less faintly clouded, the cloudy areas tending somewhat to form broad transverse bands.

Geographical distribution.—Occurs from Chesapeake Bay to the southwestern coast of Texas. The material at hand indicates that it is fairly common or abundant on the Gulf coast of the United States and the east coast of Florida. Recorded as being common on the coast of South Carolina. Probably common on the coast of North Carolina.[4] Not now recorded as being common in Chesapeake Bay.

Cynoscion regalis (Bloch and Schneider)

Common name.—Gray squeteague.

Other common names.—Weakfish (coasts of New England, New York, and New Jersey); gray trout, trout, and sea trout (Chesapeake Bay and southward).

Johnius regalis Bloch and Schneider, Systema Ichthyologia, 1801, p. 75.

Otolithus regalis Cuvier and Valenciennes, Hist. Nat. Pois. (quarto ed.), tome 5, 1830, p. 50 (in part; includes also the spotted squeteague, as shown by the statement "Il y en a une variété plus belle, à taches noires mieux terminées et s'étendant même sur la seconde dorsale et sur la caudale.").

Otolitus thalassinus Holbrook, Ichthyology of South Carolina, 1855, p. 132, pl. 18, fig. 2.

Cestreus regalis Jordan and Eigenmann, Rept., U. S. Commissioner of Fisheries, 1886, p. 366 (in part; excepting specimens from Gulf of Mexico).

Diagnosis.[5]—Vertebræ 25 (8). Anal soft rays with a modal number of 12 (127), commonly also 11 (57), infrequently 13 (5). Total number of gill rakers in individuals of 71 to 180 millimeters, standard length, with the mode at 17 (87), frequently 18 (53) or 16 (31), infrequently 19 (9) or 15 (6), rarely 20 (1), the modal number for the two

[4] After the above was written I received a letter from Dr. S. F. Hildebrand (Aug. 8, 1928), in which he said: "Yesterday I picked up in the local market a *Cynoscion nothus* and I obtained the interesting information that this fish has been taken in considerable numbers during the past few months in a pound net operated in the sea off Bogue Banks. I saw only 1 specimen in the catch of yesterday, but the manager informed me that 'a lot of them' had been taken and that during May they frequently obtained as many as 100 pounds per day. This is very interesting information, inasmuch as it was supposed that the species was quite rare in this vicinity. To date I do not know of a single specimen that has been taken within the harbor. I do not know of any fishing, exclusive of hook and line work and seining within the bight of Cape Lookout, that is done in offshore waters other than with this particular pound net. It may be, therefore, that this species is much more common in our offshore waters than was supposed."

[5] The diagnosis is based on specimens from Chesapeake Bay; Beaufort, N. C.; Winyah Bay, S. C.; and Fernandina and Cape Canaveral, Fla. In more northern localities the number of fin rays probably increases somewhat.

limbs of the first arch enumerated separately being 5+12. The tendency to fewer gill rakers with increase in the size of the fish is not as marked as in the following species. The caudal is emarginate in specimens over 300 millimeters total length, the change from a biconcave to an emarginate condition taking place when the fish reaches a total length of approximately 250 to 300 millimeters. Least depth of caudal peduncle in grown individuals usually greater than length of snout, 1.39 to 1.66 in maxillary. Dorsal soft rays have a modal number of 27 (84), the next highest class being 28 (63), frequently 26 (26) or 29 (11), infrequently 25 (5). Color, upper two thirds of body with rather small irregular pigment spots without sharply defined borders, many of the spots contiguous or coalescent, forming irregular oblique or longitudinal streaks. This typical coloration frequently faint in preserved specimens, especially in the smaller individuals. Lower third of body plain silvery gray, sometimes somewhat irridescent. Fins usually pale, without well defined spots, sometimes a few faint spots on caudal, near its base only.

Geographical distribution.—Atlantic coast of the United States from Massachusetts Bay to the east coast of Florida. Occurs also occasionally in the Gulf of Maine.

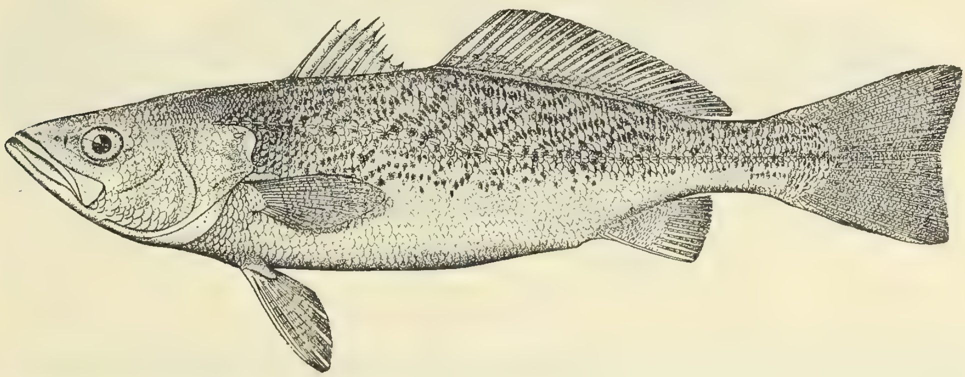

FIGURE 6.—*Cynoscion regalis* (Bloch and Schneider). Gray squeteague. Drawn by Louelle E. Cable from a specimen taken off North Carolina

Specimens studied from Chesapeake Bay, the Carolinas, and Florida. This species is evidently confined to the Atlantic coast, the Gulf form being sufficiently distinguished to be regarded as a distinct species or at least subspecies.

Cynoscion arenarius[6] sp. nov.

Common name.—Sand squeteague.

Other common names.—Sand trout (Texas); white trout (Pensacola).

Otholitus thalassinus Gunther (not Holbrook), Cat. Fish. Brit. Mus., vol. 2, 1860, p. 308.

Cynoscion nothus Goode and Bean (not Holbrook), Proc., U. S. Nat. Mus., vol. 2, 1879, p. 131.

[6] An unbiased study of the data here presented shows, I believe, that there is room for difference of opinion as to the degree of difference between this form and *ragalis* from the Atlantic coast—whether they should be regarded as species or as subspecies. I am personally averse to the use of trinomials because, first, for practical reasons such names are clumsy, and, second, even on theoretical grounds, in a consideration of the larger problems of descent, the use of trinomials is not of great help, since our understanding of the mechanism and methods of descent are too hazy, uncertain, and controversial at the present time, and the mere bestowal of a trinomial on any taxonomic unit does not help to elucidate these problems. Under the circumstances, therefore, it seems that the matter of expediency should be given consideration and the name be merely regarded as a convenient handle in discussing the particular form, in which case simplicity is desirable.

Cestreus regalis var. *thalassinus* Jordan and Eigenmann (not Holbrook), Rept., U. S. Commission of Fisheries, 1886, p. 366 (in part; specimens from Pensacola and Pass Christian only).

? *Cestreus regalis* var. *regalis* Jordan and Eigenmann (not Bloch and Schneider), loc. cit. (in part; specimens from Gulf of Mexico not being described, it is not possible to state with certainty whether they belong here or under *nothus*).

Cynoscion nothus Welsh and Breder (in part), Bull., U. S. Bureau of Fisheries, Vol. XXXIX, 1924, p. 169.

Diagnosis.—Vertebræ 25 (47). Soft anal rays with the modal number very decisively at 11 (92), sometimes 10 (12) or 12 (15). Total number of gill rakers in specimens of 71 to 266 millimeters, standard length, usually 14 (20) or 13 (19), frequently 15 (13), infrequently 12 (2). Enumerating separately the gill rakers on the two limbs of the first arch the most usual numbers are 4 + 10 or 3 + 10. The

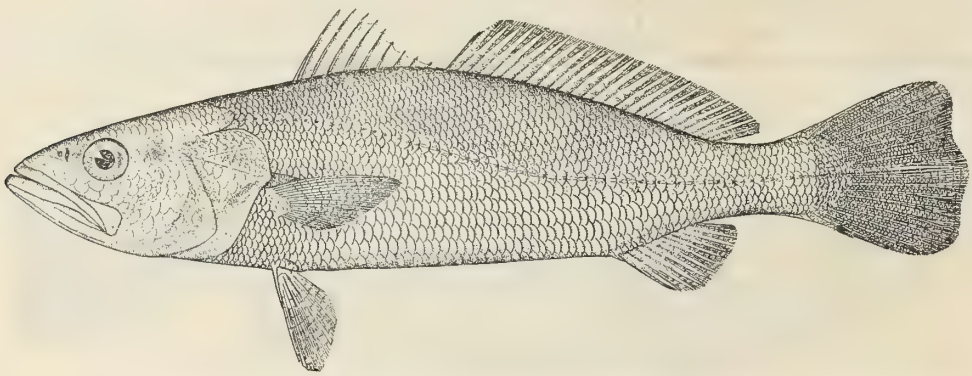

FIGURE 7.—*Cynoscion arenarius* sp. nov. Sand squeteague. Drawn by Louella E. Cable from a specimen taken off Galveston, Tex.

tendency to a decrease in the number of gill rakers with an increase in the size of the fish is quite marked; in specimens of 31 to 70 millimeters standard length the frequency distribution is as follows: 14 (6), 15 (31), 16 (24), 17 (7), 18 (1). Caudal not emarginate in individuals over 300 millimeters, the middle rays being somewhat longer (specimens up to 315 millimeters total length examined). Least depth of caudal peduncle usually shorter than snout; 1.57 to 1.82 in maxillary. Dorsal soft rays have a modal number of 26 (59), quite commonly 25 (35) or 27 (22), rarely 24 (2) or 28 (1). Color pale, without well defined spots, yellowish above, silvery below, the centers of the scales above level of gill opening sometimes forming faint oblique rows of cloudy areas. The back in young cloudy, the cloudy areas tending to form indefinite broad cross bands.

Description of type specimen.—Total length 290, standard length 245, greatest depth (60.1) [7] near tip of ventrals, 4.08 times; head (77.4 measured to posterior membranous edge of opercle) 3.17 in standard length. Snout (22.3 measured to edge of membranous border of eye) 3.47; eye (13.3 measured between membranous borders) 5.82; interorbital (16.5 measured on a level through middle of eye) 4.69; maxillary (36.2) 2.14; postorbital part of head (44.8) 1.73; least depth of caudal peduncle (21) 3.69; distance from posterior end of dorsal insertion to base of caudal on mid line (33.8) 2.29; and distance from anal opening to posterior end of insertion of anal (35) 2.21 in length of head.

[7] The number in parentheses in every case gives the actual length in millimeters.

Snout rather long, considerably longer than eye and slightly more than least depth of caudal peduncle; eye 1.68 and least depth of peduncle 1.06 in snout. Maxillary rather long, distance from posterior end of dorsal insertion to base of caudal on midline 1.07 and distance from vent to posterior end of insertion of anal 1.03 in maxillary, which extends to a vertical about midway between pupil and posterior margin of eye. Articulation of mandible on a vertical behind posterior margin of eye at a distance about equal to diameter of pupil. Outer angle of insertion of ventral on a vertical through the lower angle of insertion of pectoral. Length of ventral (about 38) less than length of pectoral (about 43). Distance from tip of snout to origin of spinous dorsal (86) 2.85 and base of entire dorsal (127) 1.93 in standard length. Origin of anal on a vertical through base of fifteenth articulate dorsal ray, its base (26.8) 9.14 in standard length, ending on a vertical through the space between the third and fourth dorsal rays from its end. First dorsal with 10 flexible spines, last one very short and almost entirely embedded in skin. Second dorsal with 1 short simple and 26 articulate rays, the last one being divided to its base. Anal with 2 short, rather feeble spines, covered with thick skin, and 11 articulate rays, the last one being divided to its base. Gill rakers 3 + 9 and 3 + 10 on right side. Vertebræ 25. Scales approximately 60 in lateral line (most of the scales of the specimen in hand have fallen off, and an accurate count is not possible). Color nearly uniform, without conspicuous spots, yellowish above, silvery below. Centers of scales on back somewhat dusky, due to concentration of minute pigment specks. Tips of lower jaw and snout blackish.

Holotype.—Cat. No. 89395, U. S. N. M. Female with developing ovaries in granular condition, February 26, 1917, Galveston, Tex., off entrance to harbor. Taken by Schooner *Grampus*, W. W. Welsh in charge.

KEY TO THE SPECIES

a. Vertebræ nearly always 27, rarely 26. Anal rays usually 9, sometimes 8, infrequently 10 in individuals from Atlantic coast only. Atlantic coast and coast of Gulf of Mexico, from Chesapeake Bay to Texas_ _ _ _ _ _ _ _ *Cynoscion nothus*

aa. Vertebræ 25. Anal rays at least 10 in Gulf of Mexico individuals and at least 11 in Atlantic coast examples.

- *b.* Grown specimens colored more or less with blackish spots, which frequently form oblique or longitudinal streaks. Caudal emarginate in individuals of over 300 mm. total length. Gill rakers usually 5+12. Snout usually shorter than least depth of caudal peduncle, which is contained 1.39 to 1.66 in maxillary. Modal numbers of soft articulate rays of dorsal and anal 27 and 12, respectively. Atlantic coast of United States. *Cynoscion regalis*
- *bb.* Color pale without definite spots. Caudal not emarginate in largest examples. Gill rakers usually 3+10 or 4+10 in specimens over 70 millimeters standard length. Snout usually longer than least depth of caudal peduncle, which is contained 1.57 to 1.82 in maxillary. Modal numbers of soft articulate rays of dorsal and anal 26 and 11, respectively. Gulf coast of the United States_ _ _ _ _ _ _ _ *Cynoscion arenarius*

KEOKUK DAM AND THE FISHERIES OF THE UPPER MISSISSIPPI RIVER[1]

By ROBERT E. COKER, Ph. D.

Professor of Zoology, University of North Carolina

CONTENTS

INTRODUCTION

With the development of the country there have ensued noteworthy changes in the condition of our streams. Deforestation, clearing of lands, drainage, all have the effect of passing the surface waters quickly into the rivers. The reclamation of swamp lands, leveeing of river banks, and dredging and straightening of river channels make it possible for the water to flow more rapidly through the rivers to the sea. The general effect, therefore, of the natural accompaniments of agriculture and industrial development is to produce extreme flood stages, both high and low, and to shorten the periods of change from one extreme to the other.

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[1] Submitted for publication Sept. 28, 1928.

Prepared at the same time and based on observations and collections made during the period covered by this report is a companion paper entitled "Studies of Common Fishes of the Mississippi River at Keokuk" (to appear in the bulletin of the Bureau of Fisheries), in which are presented the known facts of the natural history of the fishes of that region. Such information forms the background of the present study, and the two papers should be consulted together by those interested.

Under primitive conditions the surface waters of a period of heavy rainfall might have required weeks to find its way through forests and over unbroken ground to the river channel,[2] while still further weeks must have been consumed as the swollen stream wound its way to the sea through the dense swamps that bordered the normal channel. A new flood period might, indeed, have begun even before the first had passed and before a stage of extreme subsidence had ensued.

Under modern conditions a similar excess of rainfall finds not only the forests diminished but surface ditches and tile drains carefully laid out to expedite its removal from the lands to the natural channels of the rivers. Once in the rivers, it again finds its way in some measure cleared, so that it may be conveyed to the sea at a more rapid rate. The river, then, rises and overflows with relative dispatch and subsides the more quickly again to a low stage; the fluctuations of level are sharper and more extreme.

The effect of rapid fluctuations upon fish life in the stream is too obvious to require lengthy comment. We know that many of our most valued fishes move out into the shallow waters for the purpose of reproduction, and we see too often that an untimely recession of the floods leaves not only mature fishes of various sizes but also a large proportion of an entire generation of young fishes to perish in isolated overflow ponds, except as they are rescued by artificial means. Furthermore, the conditions for the development and maintenance of a food supply for fish are obviously the less favorable, the greater the degree of fluctuation in level and in expanse of the water.

One would never expect to secure the maximum production of fish in a pond that is to-day 10 acres in expanse and 20 feet deep and next week 3 acres in extent and 8 feet in depth. In any stream the fish and other aquatic animals are subject to natural vicissitudes under the best conditions, but the trend of the changes in our rivers wrought indirectly by man's alteration of the face of the land has been in a direction generally unfavorable to the growth and multiplication of fish.

Some of the changes wrought by man may be in some measure compensatory in effect, however. Of this nature we might expect, generally speaking, to be those developments that tend to control the stream flow or to diminish the degree of fluctuation of level. Among the factors contributing to the control of stream flow are improved methods of agriculture, providing for storage of water in the soil, and the impounding of waters under such conditions as to hold back the surface water in times of excess and to release it gradually in times of deficiency. Such impounded waters we may call reservoirs when the purpose is essentially the temporary storage of excessive rainfall. Another class of impounded water consists of the pools or lakes formed by dams constructed for purposes of power. With these the storage and the liberation of water may be governed largely by power demands, and their effect upon stream flow below the pool may be one thing or another, according to local conditions and according to the mode of operation of the plant. In any case, however, we are likely to find large expanses of water of relatively fixed level and affording favorable breeding and feeding grounds for many species of fish.

In the case of impounded waters classed as reservoirs, where the water is held temporarily, we look for the beneficial effect upon fish life not in the reservoir itself so much as in the stream below, the flow of which is rendered more uniform. In the case of artificial pools and lakes we look for beneficial effects primarily in the lake itself and above it, if fish should thrive in the pool and wander from it.

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[2] Rafter (1903) cites important references bearing on this question.

Dams have relation to fish life, however, in other ways than through the creation of regions of impounded waters. They constitute more or less effective barriers or obstructions in the course of the river and thus may interfere with the free passage of migratory fish from one portion of a stream to another. This, in fact, is the effect of dams that is most ever present in the public mind, and it is certainly one of great significance whenever anadromous or broadly migratory fishes are concerned.

Now it is impossible to strike a fair balance in any offhand way between losses and gains to the fishery resulting from the construction of a dam. Except as the conditions may be investigated carefully and the actual facts ascertained, at least in a number of representative cases, broad general statements are unwarranted. For any stream and for the particular location on the stream we must know if there are fishes affected that are of distinctly migratory habit, and if their migrations are of such an extent as to be interrupted seriously by the dam; and we should measure, also, as best we can, the actual compensatory benefits to fish life.

If the principal fishery of a stream is based upon the salmon, and it is known that the salmon must pass in considerable numbers beyond the site of the dam in order to propagate itself, the answer is obvious—the dam is ruinous to the salmon fishery unless the fish can be passed over it by means of proper devices. The effect of the lake in modifying the temperature of the water flowing over the dam is also a factor in this case. (Ward, 1927.) In the case of streams of another region the problem may be more complex, as when the fishery is based not upon one but upon many species, each of which may have its own peculiar habits as regards reproduction and migration.

The investigation now being reported upon was based upon the dam constructed across the Mississippi River between Keokuk, Iowa, and Hamilton, Ill., one of the greatest dams yet constructed for power development exclusively and one that affected one of the principal streams of the United States. Such effects as this dam might have would be felt locally both above and below the dam; they might also be felt at points hundreds of miles away from the dam, above it and, perhaps, below it as well. The investigation was begun in 1913 and was continued, with some interruptions, to 1927. There were several reasons why a period of years was required for the study. In the first place, we knew little regarding the extent of the necessary migrations of the common fishes of the Mississippi River; in the second place, the catches of fish under normal conditions vary widely from year to year, and the conclusions drawn from one year's observation might well be entirely misleading; finally, it was recognized that the effects, both good and bad, might display themselves only after a period of years. The diminution or the increase in abundance of a particular fish might be directly attributable to the dam, although not observable in a practical way until after several years. We do not now assume that all effects of the construction of the dam at Keokuk have yet been realized, but we believe that there is ample warrant for the presentation of a report and for a statement of the conclusions that are drawn.

Circumstances beyond the power of the Bureau of Fisheries to control led to the virtual termination of field observations at Keokuk in 1917 and to delay in completing all the studies necessary for report. A considerable portion of our data, however, was thoroughly organized and put in preliminary report form in 1918. The delay in publication has not been unfortunate, because it is now evident that had conclusions based upon statistical reports been published in 1918 it would have

become necessary substantially to revise them in the light of data made available in 1922 and 1927 from the statistical canvass for those years. "Time will tell"—particularly in the case of a substantial alteration of conditions in a natural watercourse.

The conclusions we have reached regarding the effect of the dam at Keokuk upon fish life in the Mississippi must not be held to be applicable to any other dam except as the conditions may be strictly comparable. It is our hope, however, that the observations we have made and the data we have brought together throw some light upon the general question of dams in relation to strictly fresh-water fishes and also contribute something to our knowledge of the habits of fishes of the upper Mississippi River.

We are well aware that there have been other significant changes in the river in recent years besides those associated with the dam. Notable among these are the changes arising from works in aid of navigation, from the development of drainage districts, and from increase in the amounts of sewage and industrial wastes discharged into the stream. It will be seen in our discussion of the changing conditions of the fisheries that we have not lost sight of such factors, and we believe that our data are so presented that it can fairly be judged whether or not our conclusions with regard to results following from the dam are justified.

The report is based upon observations and other data gathered in the manner indicated in the following paragraphs:

While the investigation was under the continuous direction of the author from its beginning in 1913, his personal visits to Keokuk and to other points on the river above and below Fairport, Iowa, were made only at intervals, and most frequently during the first two years of the investigation, when he was stationed at Fairport on the banks of the Mississippi. Emerson Stringham, scientific assistant, who entered the investigation in the second year, made occasional visits to Keokuk and other points during the winters of 1914–15 and 1915–16 and the summer of 1917 and remained on the ground at Keokuk for continuous observation during such portions of the years 1915 and 1916 as the river was not frozen over. Direct observations at Keokuk were discontinued in 1917, when a preliminary report was prepared.[3] An interval of years was then allowed to elapse, during which the reality of seeming trends might be tested by the results of later statistical studies. The last personal observations by the author were made in 1926, when he visited a number of points on the river between Lake City, Minn., and Canton, Mo. The chief object of this last trip was to check, by personal interviews with fishermen, the impressions derived from the study of statistical reports.

Free use has been made of all available published data regarding the distribution and natural history of the fishes considered in this study. The records of collections and observations of fishes made by the various members of the staff of the Fisheries Biological Station at Fairport, Iowa, and its field party on Lake Pepin (Minnesota–Wisconsin), though not brought into this report in detail, have been invaluable.

[3] Soon after the preparation of this report Mr. Stringham left the bureau, and since that time the report has been extended greatly and otherwise modified in the light of new information. The senior investigator proposed to adhere to the original arrangement for joint authorship, but when the completed report was submitted to Mr. Stringham he replied that it would not be right to have his name upon it as joint author. The present author takes this opportunity to say that Mr. Stringham's contributions to the report were very valuable, consisting in observations made on the river (especially at Keokuk), in the discriminating judgment applied to the observations, and in the assembling of literature. In regard to the literature, the present writer has personally examined nearly all of the publications for which references were obtained by Mr. Stringham and has been able to add a good many more. He assumes full responsibility for the conclusions drawn from the study, but it is not out of place to say that the final conclusions differ from those that were formed jointly in 1917 in only a few important particulars, as to which revision of judgment was made inevitable by the accumulation of new data.

The continuity of such collections, made for other purposes summer after summer, have afforded many suggestions and served as a check upon premature generalizations.

A study of the plankton, or minute fish food, of the lake and of the river above and below and an examination of the distribution of aquatic vegetation in the lake were made by A. A. Doolittle in 1914. War conditions prevented a repetition of this survey after a period of two or three years, as was considered necessary for the best use of such data for purposes of deductions.

In the summer of 1921 Dr. Paul S. Galtsoff, of the United States Bureau of Fisheries, studied the composition, amount, and distribution of plankton in various parts of the Mississippi River from Lake Keokuk northward to Hastings, Minn., a few miles above Lake Pepin. His observations and conclusions have already been published by the bureau. (Galtsoff, 1924.)

Statistical canvasses of the fisheries in Lake Pepin and in Keokuk Lake (sometimes called Lake Cooper [4]) were made in 1915 by W. A. Roberts (for the year 1914), in 1918 by Arthur Orr (for the year 1917), in 1923 by various agents (for the year 1922), and in 1928 (for 1927).[5]

Another source of valuable information was found in the regular records of fish stranded on the top of the lock gates during 1915, 1916, and 1917, kept by lock masters William Huele, Timothy Harrington, and Walter Raber by direction of Montgomery Meigs, civil engineer, United States Army.

The officers and employees of the Mississippi River Power Co. have been uniformly considerate and helpful, extending to the investigators free access to all parts of the plant as necessary for the purpose of investigation and furnishing all information requested as well as several of the photographs used in this report. The cooperation of United States Engineer Meigs in allowing the regular use of a trammel net on the top of the lock gate during several months of 1915 and the assistance of lockmen in the operation of the net deserve special mention. Many fish dealers and fishermen (of Keokuk especially and of other places as well) have freely furnished information that has been indispensable to the effective conduct of the investigation, but their names are too numerous to mention.

Grateful acknowledgment is also made for the opportunities and the encouragement extended by former Commissioner of Fisheries Hugh M. Smith and Deputy Commissioner H. F. Moore and, more recently, by Commissioner of Fisheries Henry O'Malley and Elmer Higgins, in charge of scientific inquiry.

KEOKUK DAM AS A POSSIBLE OBSTRUCTION TO FISH

The dam has been described at some length in a previous report,[6] and it is unnecessary to repeat the details in this report. The features of the dam most essential for a correct understanding of its relation to fishes may be stated briefly in the following way:

Its location is across the Mississippi River, 1,435 miles by river from New Orleans (about 1,545 miles from the Gulf of Mexico) and 490 miles by river below

[4] The name Lake Cooper was originally given to the body of impounded water above the dam and therefore was employed by the bureau in preceding reports. The change in the present report to the use of the name Lake Keokuk is occasioned by the action of the U. S. Board on Geographic Names, which has officially sanctioned the latter designation. To avoid the possibility of confusion, however, it seems advisable to state that our remarks refer in no case to the locally well-known Keokuk Lake of Muscatine County, Iowa.

[5] The results of these canvasses, frequently quoted in this report, are found in full in the following publications: Reports, U. S. Commissioner of Fisheries, for 1916, pp. 58–60; 1918, pp. 75–80; Sette, 1925, pp. 210–212; and Sette and Fiedler, 1929.

[6] Coker, Robert E.: Water-Power Development in Relation to Fishes and Mussels of the Mississippi. Appendix VIII, Report of the U. S. Commissioner of Fisheries for 1913. Bureau of Fisheries Document No. 805, pp. 11–18.

the head of navigation at Minnehaha Falls, near St. Paul, Minn. It is a little above the halfway point between Lake Itaska and the Gulf of Mexico (a distance of 2,553 miles). It is above the greater tributaries—the Missouri (200 miles) and the Ohio (375 miles). In fact, no regularly navigable streams or waters enter the Mississippi above Keokuk except the Rock River and Hennepin Canal, connecting with the river just below Rock Island, Ill., and the St. Croix in Minnesota. The tributary streams of most direct possible effect upon the dam are the Des Moines, about 3 miles below the dam; the Skunk River, entering the lake 35 miles above the dam; the Iowa River, 72 miles above the dam; and the Rock River, 119 miles above.

The site of the dam is just at the foot of the old Des Moines Rapids of the Mississippi, where the valley is comparatively narrow. (Figs. 1 and 2.) "The river at this place, in its natural condition, is about 2,600 feet in width at ordinary low water and about 5,500 feet in width at flood stages." (Clark, 1911, p. 203.) The dam, with its abutments, is nearly 1 mile long, and the fall is 32 feet, more or less, according to the stage of river level above and below. Low water just above the dam, which was formerly about 485 feet, is now 519, referring to the Memphis datum. High water was formerly 505 and is now 525. The pool, or Lake Keokuk, extends to a point a little above Burlington, or about 40 miles above Keokuk. The expanse of the lake is approximately 60 square miles—actually 58 square miles at low water, as compared with 36 square miles of river surface in former times at low water, and 64 square miles at high water as compared with 54 square miles in former times at a corresponding volume flow of the river.[7]

Returning to the dam, we find, beginning from the Iowa shore, the Government shipyard and dry dock, the lock (110 by 400 feet), and a short section of dam connecting the upper end of the lock with the lower end of the power house, which stands in the river 700 or 800 feet from the Iowa shore. Although the lower half of the power house is unfinished, except for its foundation (an integral part of the dam), the entire structure is one-third of a mile long. It extends upstream and nearly parallel with the Iowa shore to connect with the west end of the dam proper, which in turn extends across the river a distance of four-fifths of a mile to the Illinois shore.

We will now examine each of the principal structures constituting the dam (the dam structure, the power house, and the lock), as regards the general relation of each to the movements of fish. Additional details will be found in the companion report, in which the several species of fish are considered separately.

THE DAM PROPER

The dam structure is composed of 119 spans, each consisting of two piers supporting an arch, while the arches uphold a causeway. Between the piers are spillways, over which the water flows. Each of these spans measures 36 feet, center to center, the spillways being 30 feet wide and the piers 6 feet. The height of the spillways is 32 feet; their upstream face is vertical and the downstream face an ogee or compound curve, delivering the water in a horizontal direction down the river. For the protection of the base of the dam from scouring, a broad, low, concrete apron has been constructed.

Between the top of each spillway and the under side of the overhanging causeway is an arched opening about 19 by 30 feet (5.1 by 9.1 meters), which will permit

[7] Information supplied by the Mississippi River Power Co. by letter dated May 19, 1927; high water corresponding to a flow of 300,000 second-feet and low water to a flow of 50,000 second-feet.

Figure 1.—Keokuk Dam and associated structures—dam, power house, lock, dry dock, and U. S. Engineers' offices and buildings

Figure 2.—The river as it appeared before the dam was constructed. Looking eastward over the old "Des Moines Rapids," December, 1910

Figure 3.—The surging waters below the open spillways

the passage of ice and drift when the gates are open. The gates are of steel, 11 by 32 feet (3.4 by 9.8 meters), and, working in deep slots in the concrete, may be raised so as to give free passage to the water or may be lowered so as to hold back the water entirely, except such as washes over when the wind is high and such as escapes by leakage. The volume of water passing Keokuk, and therefore the water levels above and below, is regulated by opening and closing these gates. The variations in the number of gates that are open is said to range from none to 100. One hundred and six observations made during the period April 16 to September 15, 1916, each on a separate day, and one or more at nearly or quite every hour of the day and night, showed a range of 2 to 57 and an average of 28+. The average for the whole year, including the period of low water in winter, might well be much less. On June 9, 1915, 74 gates were seen to be open at one time. The gates are raised and lowered by a traveling electric crane, and a complete operation, including the movement of the crane from the adjoining gate, required about 26 minutes previous to 1916; during that year improvements were made, so that a complete operation could be performed in about 6 minutes, and only one crane is needed now.

The head, or difference in water levels, varies considerably, being affected by flood conditions above and below the dam and doubtless by backwater from the Des Moines River prior to July, 1917; according to information supplied by the power company, the head on the turbines had been as low as 21 feet and as high as 37 feet; it was thought that the head at the dam might be as much as 1 foot greater. When a gate is open there flows over the spillway a stream of water about 10 feet deep (at the crest) by 30 feet wide.

We thus have at each spillway in use a waterfall of considerable volume, deflected at the bottom, where the water shoots out with tremendous force in the form of a raging, foaming torrent, which makes a striking spectacle. Only an inadequate idea of it can be gained from Figure 3. The mass of rapid water cuts a deep, sharp trough in the surface of the river, so that the surrounding water is at a considerably higher level than the race water below the open spillways. It may be possible to grasp this from the figure; the dark area in the foreground is the relatively still water, which is always flowing down into the trough made by the water coming over the dam. During most of the year the water makes a terrific commotion when it hurls itself against rocks that extend above the surface of the water. When the stage of the lower river exceeds 11.34 feet (or 495 feet, Memphis datum), all rocks, as they existed in 1916, are submerged. The turbulence of the water is then less spectacular, but the force is still so great that no fish can get to the base of an open spillway. They do, however, come to the dam at a point where spillways are closed, and often work along the base until they are carried by the eddy into the troughlike race, by which they are instantly swept down the river. Sometimes a fish drawn into the edge of the race in this way is tossed high into the air; but in any case its inability to stem the swift current is manifest.

It is evident then that the dam itself (as distinct from the power house and lock) is insurmountable for fish coming from below. Not only can fish not ascend the spillways, but they can not even buffet the current for a distance of several hundred feet below the open spillways.

There are several conditions that might cause fish to approach the base of the dam. In the first place, if there were an upstream movement at the time of the reproductive activity, the fish naturally would be led to follow the swift current as

far as it was possible to do so, and as they skirted the main streams from the spillways they would be led in many cases to the base of the dam. In the second place, the aeration of the water would be highest just below the falls, and this condition might be attractive to fish, particularly just before the season of reproduction. Finally, it is not unlikely that a good deal of food is brought over the dam from the pool above, which would serve as bait to draw the fish as near as possible to the dam. Whatever the cause, it seems to be a common observation that fish are found abundantly below dams at certain seasons and particularly in the first years after the construction of a dam. The investigators have, therefore, kept a careful watch for aggregations of fish, of any species at or near the base of the dam. Conspicuous aggregations of fish, however, have rarely been observed at Keokuk, occurring much less frequently than was expected and apparently with no regularity.

While our visits were only occasional during 1913, 1914, and 1917, it must be kept in mind that an observer was in regular attendance during two complete open seasons—1915 and 1916. The first recorded aggregation of fish was reported by Thaddeus Surber in 1913, only a few weeks after the dam was closed. (Coker, 1914, p. 10.) Fish were seen first below the dam on July 10 and 11 in such numbers that local residents captured them not only with hook and line but with dip nets and hayforks. The fish seemed to have been found in the following order of abundance: Buffalo, carp, paddlefish, sheepshead, drum, channel catfish, redhorse, Missouri or blue sucker, toothed herring, and hickory shad. It may be remarked that many of these fish are not particularly migratory.

The next conspicuous aggregation of fish was observed by the writer in the following year on April 29, when only one species, the river herring, was in evidence. The distribution of the herring on this occasion has been described in the following words (Coker, 1914, p. 25):

> The day of my arrival, April 29, was cold, windy, and cloudy, and at first view very few herring were observable. After closer observation, however, they were seen to be present in immense numbers, and congregated in certain locations * * *. A large number were seen just below the short section of dam between the upper end of the lock and the lower end of the power house; many were observed along the outer wall of the tailrace, but in the angle between the power house and the dam and from this point to the nearest open spillway, a short distance away, the herring were fairly massed. Such a close aggregation of fish can rarely be seen in fresh water. They had evidently followed up along the outer edge of the tailrace until they could go no farther. Again, on the outer side of the last spillway in use, which was about 700 feet from the power house, there were considerable numbers of herring. From this point to the Illinois shore, a distance of about two-thirds of a mile, not a single herring was in evidence. It was evident, therefore, that the herring had been guided by the moving water, so that they had in consequence assembled in such remarkable numbers on each flank of the stream below the open spillways, many more being guided to the eastward side by the strong current from the turbines.
>
> Opportunity to observe whether they could breast the strong current was favored by the fact that there were three closed spillways between three open on the east and nine open on the west; thus, there was a triangle of relatively slack water between two strong currents that met a short distance below. To the west of the westward current fish were abundant; to the east of the eastward current they were still more abundant; but in the triangle between not one fish could be seen. It was evident, therefore, that the power of the currents below the spillways proved an effective barrier to the lateral movements of the fish for some distance below the dam, otherwise not all of the fish would have been on the right side of one current and on the left side of the other.
>
> The powerful currents caused slight eddies on each side, so that the dead water at the foot of the dam on either side was continually being drawn into the spillway streams. The fish were also drawn in, and it was easily observed that the velocity of the streams made them perfectly helpless. As soon as they passed into this stream they were thrown up in the foam and spray and often hurled

20 feet or more, back, sides, or underparts up, to be carried off as soon as they fell. Presumably no injuries were received, as no dead or injured fish were observed in the river below. No fish, as previously indicated, were drawn in from the slack water between the easterly spillways and the westerly, although similar eddies prevailed here.

This remarkable aggregation of a fish, presumed to be one of the most migratory in the river, seemed to be especially significant, and we expected that it would be repeated in the following year. However, this expectation was not realized, and it will be seen later that other observations give ground for the belief that the herring is established both above and below the dam. (Coker, 1930.)

In spite of the closest observation in the spring and summer of 1915 and 1916 no extraordinary gatherings of fish other than gar pikes and carp were observed by Stringham. An extraordinary aggregation of carp that occurred near the lock on July 17, 1916, is illustrative. The fish were just below the short section of the dam connecting the lock and the power house, or at the bottom of the chute used for passing over the drift that accumulates in the fore bay above the lock. Thousands of carp were visible at any moment. In this case the occasion of the assemblage of carp was fairly obvious. On July 13 and 14 there had occurred a noteworthy flight of May flies, and millions of them had drowned in the lake. On the 15th the prevailing wind was from the southeast, but on the 16th it was from the north and on the 17th from the northeast. An enormous and noisome mass of May flies, May-fly casts, and duckweed had drifted toward the lock and was flowing in a steady stream through the chute. The carp were snapping up the May flies and duckweed at the surface. Nine of the carp were opened and the stomachs of seven were found to contain principally adult May flies, with some duckweed and the remains of the weed; two were empty. Early the next morning both fish and May flies had disappeared. Later observations on the 19th, 20th, and 21st indicated a recurrence of carp in noticeable numbers associated with a north wind and the presence of the floating food.

While the dam serves as a barrier to upstream movements of fish so far as the dam structure proper is concerned, it is of interest to know if it is in any way a barrier to downstream movements. Observations upon this point are not complete or satisfactory. Fish can and do pass over the spillways, but we do not know that this occurs at all frequently. It is probable that the lake itself operates as a sort of barrier, in that deep still water provides such habitats for fish in downward migration as to inhibit the tendency to move down the river. Certainly, so far as a downward migration is the result of drifting with the current, the relatively slack waters of the lake would serve as an automatic check.

During the latter half of July and August, 1916, when May flies were very abundant immediately above the dam, fish were frequently seen to break the surface, but, on the whole, fish were not often in evidence in the surface waters of the lake near the dam. On August 2, 1915, a number of fish were seen above the western end of the dam, swimming near enough to the surface to make conspicuous wakes. Commonly they swam down near the crest of the dam and then suddenly turned back, but sometimes they were seen to go over the spillways. Such observations could be made only when the fish swam close to the top of the water. It is reasonable to infer that this occasion was not an isolated one and that the fish do go over the spillways from time to time. Several experiments mentioned in another connection show that the goujon (*Leptops olivaris*), the carp, and the paddlefish may go down the spillways and through the turbulent waters below without injury.

So far, then, as regards the dam structure proper, which comprises about three-fourths of the total barrier, we find that no fish can pass upward but that the fish may pass down, particularly those that feed or swim near the surface. The vertical upstream face of the spillways is a factor that must tend to lessen the chance of bottom fish being drawn over with the current. Aggregations of fish at the base of the dam, as if endeavoring to find a way up, have been observed, but with no such regularity as might have been expected. In the few instances, when such conspicuous gatherings of fish came under notice, different species were present each time, and in one case the presence of food brought over the dam was the obvious occasion for the gathering. Such observations do not afford adequate basis for dismissing the possibility that the dam acts detrimentally as a barrier to upstream migrations, and this question will be considered more carefully in later sections of the paper.

POWER HOUSE

The power house, built out in the water and nearly parallel to the Iowa shore, from which it is some 700 or 800 feet distant, forms the eastern boundary of the fore bay. It may be remarked that the fore bay is a semi-inclosed portion of the lake, bounded below by the lock and the dry dock, on two sides by the power house and the Iowa shore, respectively, and above by a long ice fender of concrete, which extends from the upper end of the power house to the Iowa shore, being interrupted by a wide opening of about 300 feet for the passage of boats between fore bay and lake.

The superstructure of the power house is completed for only one-half of the total length as planned (1,718 feet), but the entire foundation walls are in place, being essential to hold back the upper water. The outside wall toward the Iowa shore is not built solidly to the bottom but rests on a series of arches, so that the water from the fore bay has free access to an inner or head bay within the building and extending its entire length. The outer wall of the building, which faces the Illinois shore, rises from the downstream bed of the river and is flanked by the tailrace. (Fig. 4.) The head bay and the tailrace are connected by as many passages as there are turbines, and each main passage consists of four narrow intake passageways; a single large scroll chamber, 38 feet in diameter, around the turbine (fig. 13); the turbine chamber; and the draft tube below. The turbines, of which there are now 15 installed, are arranged in a single linear series from end to end of the house. The tailrace itself is excavated about 25 feet below the bed of the Mississippi; its width is 80 feet at the end, broadening to 230 feet at the lower end of the power house; the precise width below this point does not appear to be known, but the excavation was carried considerably farther down.

The water from the head bay is admitted to each turbine through four gates, each 22 feet high by 7 feet 6 inches wide, consisting of iron gratings, which prevent the passage of large drift but which can exclude only those fish that are of unusually large size, the openings being 6 by 23 inches. The structures within the buildings are more particularly described later in discussing injuries to fish. It is sufficient at this point to state that upward movements of fishes would be stopped absolutely by the turbines. Undoubtedly it would be impossible for a fish to pass upward from the tailrace, through the draft tubes, and beyond the turbines.

To find passage downstream through the power house, a fish must first pass the ice fender, either through the boat channel or through the deeply submerged archways; it must then enter the power house through the arches of the foundation

Figure 4.—Turbulent tailrace west of the power house; the outlets from the turbines are beneath the surface on the right

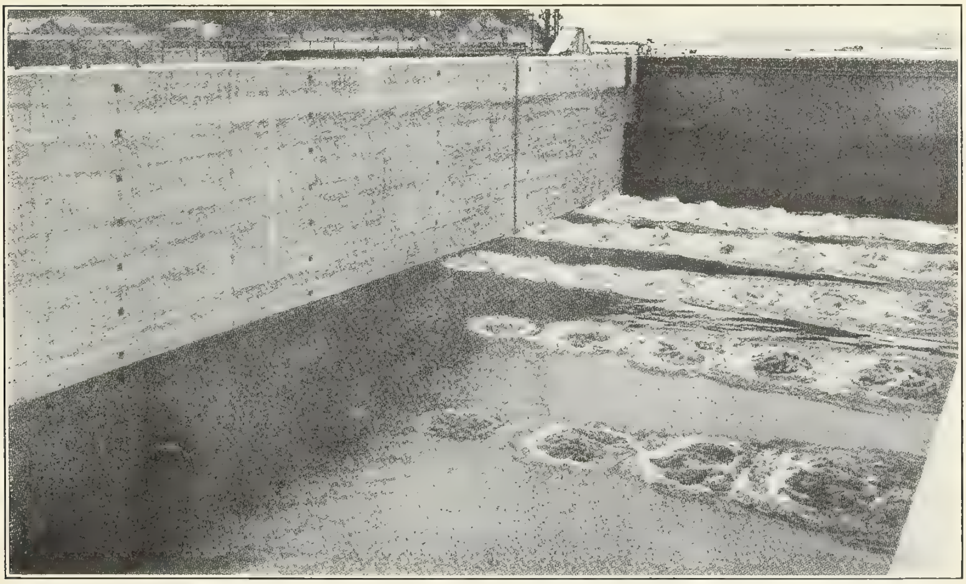

Figure 5.—Lock being filled through a series of culverts with openings into the bottom of the lock. The valves have just been opened, so that the locations of only about 30 of these 3-foot openings appear in the illustration

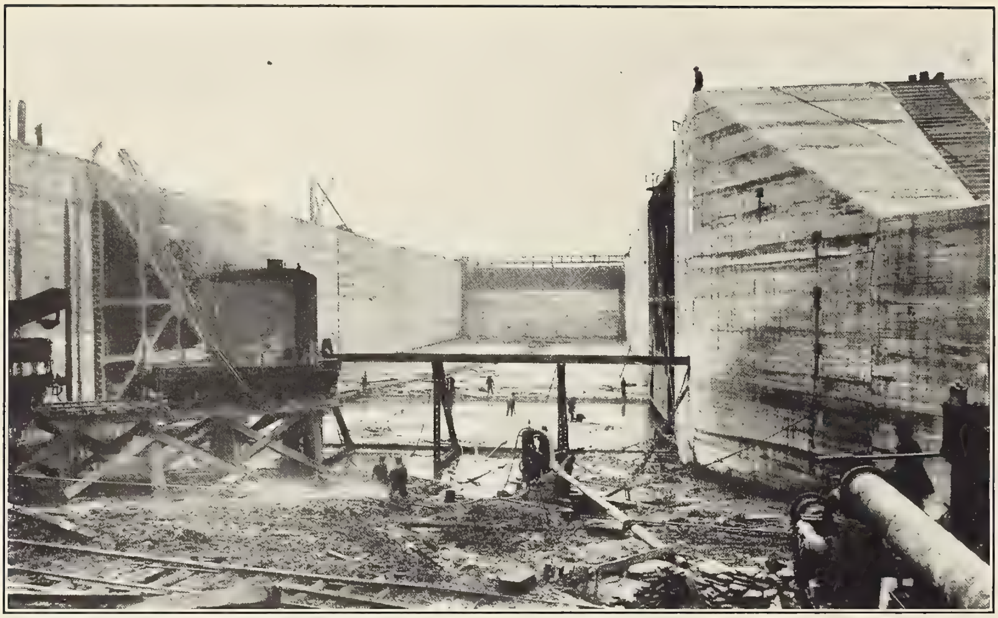

Figure 6.—The lock as it appeared in course of construction. Looking upstream into the lock from below the lower gates which are swung back into recesses in the walls. The head wall and head gate are seen in the background

Figure 7.—Setting a trammel net on the top of the lock gate to determine from which side the fish come

walls. Having passed these partial obstructions, it encounters the screens or gratings at the gates of the intake passages. The openings in the gratings (6 by 23 inches) are wide enough to admit most Mississippi River fishes but so close that a downward-moving fish probably would be deflected just as fish are deflected by the wide-meshed leads of a trap net. The investigators never saw a fish near the screens, except one or two that were put into the water for experimental purposes. The power company's guide, who walked by this head bay several times a day for nearly two years, stated that he never saw a fish here prior to April, 1915; on April 4 he said that a few days before he had seen four or five fish. Obviously, however, only surface-swimming fish would be observable, and it may be that such are deflected more than bottom fish by the ice fender and the arches of the foundations of the power house.

A fish passing into the power house from above, through the screens, would nowhere find a narrower passage than the screen afforded, except in a single unit where the vanes admitting water from the scroll chamber to the turbine have an opening that is only about 5 inches wide, according to information supplied by the power company. Usually the opening between the vanes (fig. 13) is about 9 inches (23 centimeters). It may be remarked that the clearance between the vanes and the blades of the wheel is large enough to pass any fish of the locality. The blades or buckets of the wheel or turbine are 6 to 7 inches apart above, widening downward to 10 or 12 inches. It seems altogether likely that nearly any fish that passed the screens guarding the entrance above could continue with the current of water through the turbine chamber and draft tubes into the tailrace below. Experiments subsequently to be described (p. 112) show the possibility of their going through unharmed.

LOCK

The lock, which serves the uses of navigation, is between the power house and the dry dock. It is of particular interest, as it is the only passageway by which fish may go from the lower river to the upper, and it has been suggested that it might function as a fishway. The inside dimensions are 110 by 400 feet; the lift varies with the head, which is nearly the same as that on the turbines. The lower gates swing open while the upper gates submerge, working up and down in vertical slots. There are, in fact, two gates at the upper end—the ordinary "upper" gate, which is used regularly, and above this an emergency or guard gate, which is normally submerged. Water is admitted to and emptied from the lock through a series of culverts, the main running under the eastern wall of the lock, and having connections with both levels; either or both connections may be closed by valves. Branch culverts from the main run beneath the floor of the lock, and openings in these admit the water into the lock in a series of geysers, as shown in Figure 5, or permit it to run out when the upper valves are closed and the lower ones opened.

It will be inferred from the description that fish would not be likely to enter the lock from below during the process of emptying, as to do so would be to pass through deeply submerging, sharp-angled tunnels, out of which the water is discharging at a velocity that is enormous until the lock is nearly empty. Likewise, they would not gain the upper lake from the lock during the process of filling at a corresponding velocity; furthermore, the intakes are screened by gratings, the openings of which are irregular in size, varying from 1⅞ to 2⅜ inches. So far as it has been possible to learn by inquiry, no fish was ever seen to pass out here, and probably none ever has.

Another significant feature of the lock is the head wall, locally called a "sill," at the upper end of the lock. An examination of Figure 6, from a photograph taken while the lock was unwatered, will give an idea of this particular difficulty to be overcome by a fish using the lock to pass upstream. In the illustration the two swinging lower gates are shown wide open and in their niches in the respective side walls; the wall or sill is in the middle background. A fish entering the lock finds a depth of 10 to 25 feet of still water. The lower swinging gates having been closed, the water is admitted in miniature geysers, as shown in Figure 5, until, after 7 or 8 minutes, it is from 21 to 37 feet (6.5 to 11.3 meters) higher than when the lower gates were closed. The upper gate (black in fig. 6) is submerged until its surface is level with the upper wall, shown light in the background. The fish is now in an inclosure 110 by 400 feet (33.5 by 122 meters) containing about 47 feet of still water. The only exit is the area 110 feet wide and 12 to 14 feet deep over the wall or sill. There is no current to guide the fish to this small opening at the upper edge of one part of a large area of concrete, and, as will be shown hereinafter, this opening exists for only a few minutes, the water being then lowered to the level of the river.

INTERVALS OF FREE PASSAGE

As has already been pointed out, there is no opening by which fish may leave the lock above, except while the upper gate is down. An effort was therefore made to learn during how much of the time this gate is submerged. Since the lock masters' records show the number of lockages, it was necessary only to learn how long, on the average, the gate is down at each lockage.

Without any selection, and just as happened to be convenient, 54 ordinary operations were timed. These operations were made in the usual way for the passage of boats, and, except in a few instances, the persons doing the work did not even know that an observation was being made. The gate remained beneath the water from 1½ to 17½ minutes, and the average for the 54 cases was 4.5 minutes. Of these, there were for the passage of boats northward 29, averaging 3.3 minutes, for the passage of boats southward 22, averaging 6 minutes, and for the simultaneous passage of different boats into and out of the upper end of the lock 3, averaging 4.5 minutes. The longer average time for boats passing downward was due to the fact that for steamboats it was the practice to have the gate ready a few minutes before the boat arrived, so as to run no risk of causing it to stop above the lock. Steamboats passing up out of the lock simply cast off from the wall of the lock and leave, so that there is no corresponding delay. For smaller craft the time of submergence was not affected by the direction in which they are going.

To allow for this difference, and because the observed cases include 7 more "ups" than "downs," we may add 7 imaginary "downs" of 6 minutes each to the 54 observed cases, which gives an average of 4.7 minutes. To simplify the arithmetic involved, 5 minutes will be taken as the average time when there exists a possible passageway for fish during each operation of the lock.

In 1915 the lock was operated from March 1 to November 29, inclusive, or 274 days, and the total number of lockages was 1,489, being an average of 5½ times a day, or almost precisely 38 times a week. Complete records for 1916 are not at hand, but during the 114 days from March 24 to July 15, inclusive (the season of supposed upward migration of fish), there were 477 lockages, an average of 4.2 times a day, or 30 times a week. The actual number per week (excluding fractional weeks

at the beginning and end of seasons) during this year and a half varied from 2 to 89; but there were only two weeks with more than 58 lockages. During the first half of 1916 the largest number in one week was 49.

Taking the average of lockages per day as 5 and the average time per lockage as 5 minutes, there was an opening for fish of 25 minutes a day, on the average, or 2¾ hours in a week. The maximum opening in any week during the year and a half in question, excluding two extreme cases, was about 4 hours. Or, to present the figures in one more form and using the same average time per lockage, there was, during the year 1915, an opening for fish for a period of time equivlent to 5⅙ days, and during the first half of the calendar year 1916 (including July 1) 1⅛ days.

EXTENT OF FISH MOVEMENTS DURING INTERVALS OF FREE PASSAGE

The facts already adduced show that there was but little time when a fish had even the slightest chance to pass out of the upper end of the lock. It has also been indicated that the situation was unfavorable during these brief intervals because of the lack of current and the relative smallness of the exit. Certainly, the lock is not entitled to be considered a fishway unless, in spite of these adverse circumstances, there is a dense mass movement of fishes leaving the lock when the upper gate is submerged. The evidence available as to the extent to which fishes move over this upper gate will now be considered.

It will be understood that a trammel net consists of three nets put together, sandwichlike, the middle one, called the "web," being of small mesh and the two on the outside, called the "walls," being of mesh much too large to stop any fish that it is expected to catch. A fish striking the net with appreciable force pushes the web through the opposite wall and thus pockets itself. Figure 7 will perhaps show this more clearly than the description.

A trammel net with web of 2-inch (5-centimeter) mesh between knots and wall of 8-inch (20-centimeter) mesh was supported on the gate by means of three 13-foot (4-meter) pieces of gas pipe, these having the net tied to them and being in turn supported in three holes bored into the respective ends and the middle of the gate. Wedges held the bottom or lead line of the net fast to the gate, and corks kept the other edges at the surface of the water. During part of the first month the cork line would go a little beneath the surface at one end, but this was corrected by doubling the number of corks. When the gate was down the only possible passage was closed by the net, except as hereinafter stated. (Fig. 8.) Operations of the gate were made especially for this work. To give fish an opportunity to enter the lock the lower gates were left open a half hour or more (except on April 3) before closing them and filling the lock. Sometimes they were open 8 or 10 hours; the average was about 2 hours. Leaving the lower gates open for this length of time made the circumstances slightly more favorable than is normally the case; but it would be entirely possible to have the lower gates left open nearly all the time, and the circumstances during the experimental work were, therefore, no more favorable than they might readily be made were it found worth while to do so.

A fish might pass the net at either end through a space between the net and the wall of the lock, possibly 1½ feet (½ meter) wide at the widest part. A trammel net is designed to catch fish on their first contact with the net, and there is probably little passing of the fish along the net toward the ends; however, a few individuals undoubtedly went through at those places. The only other way that a fish too large

to go through a 2-inch mesh could get past, with the net on the gate, was by passing downward through one of a series of horizontal openings between the beams of the gate and then under the walk of the gate. These openings are shown in Figure 9. They are not rectilinear; of the eight, six measured about 3 by 8 feet (1 by 2½ meters) and the others were smaller. In order to find these openings a fish would have to descend sharply into a narrow passage without an obstacle to guide him downward. It is possible that some fish of bottom habit might make this sharp descent, but these are the fishes least likely to surmount the wall at the upper end of the lock.

The first operation with the net on the gate was made on March 25, 1915, and the last on August 25 of the same year. Excluding three days, the record for which was lost in a notebook that fell into the water, 94 operations were made—1 in March, 28 in April, 23 in May, 21 in June, 17 in July, and 4 in August. A schedule, conformed to as closely as the exigencies of navigation allowed, provided for different hours on each day of the week—from 3 a. m. to 11 p. m.

In the net itself there were caught about 46 Ohio shad (all but one taken from the lock side), 11 bigmouth buffalo, 2 each of longnose gar and river herring, and 1 each of smallmouth buffalo, river quillback, sauger, mooneye (Alosoides), and bowfin. During these operations many more fish were caught on the surface of the gate than in the net. The net was run diagonally across the gate, bisecting its surface. Except on the first day, note was made as to whether fish lay on the side toward the lock ("below") or on the side toward the lake ("above"). The total of all fish taken in the net and on the gate during the 94 operations was 167 above, 457 below, and 7 not noted. These were distributed among the various species as follows:

TABLE 1

Species	Below	Above	Not noted	Total
Longnose gar	2	2		4
Shortnose gar	21	5		26
Bowfin		1		1
Mooneye (Alosoides)	4			4
Mooneye (Tergisus)	4			4
Mooneye (lost before identified)	1			1
Gizzard shad	23	1		24
River herring	2			2
Ohio shad	45	1		46
Eel	1			1
Bigmouth buffalo fish	20	1		21
Smallmouth buffalo fish	8	2		10
Buffalo fish (lost before identified)			1	1
River quillback	206	87		293
Quillback (Difformis)	3	1		4
Quillback (lost before identified)	1			1
Shorthead redhorse	6	1		7
Quillback or buffalo (lost before identified)	1			1
German carp	6	2		8
Shiner (Atherinoides)	1			1
Spotted cat	52	32		84
White crappie	7	9		16
Black crappie	3	2		5
Bluegill	2	1		3
Walleye	2	1		3
Sauger	5	3		8
White bass		1		1
Yellow bass	1			1
Fresh-water drum	30	14	6	50
Total	457	167	7	631

This is a representative list of the commoner species found about Keokuk during that year, except for the omission of the minnows, goujon, and two species of the current—shovelnose sturgeon and Missouri sucker (blue sucker). Nearly all species were taken more numerously from the lock side than from above. This was due partly, at least, to

FIGURE 8.—The gate down and the corks keeping the top of the net afloat. Fish passing out of the lock, upstream, and into the lock from the lake, downstream, will be pocketed on different sides of the net

FIGURE 9.—The gate has been rasied, one fish having been caught in the net. Large catches were made on several occasions

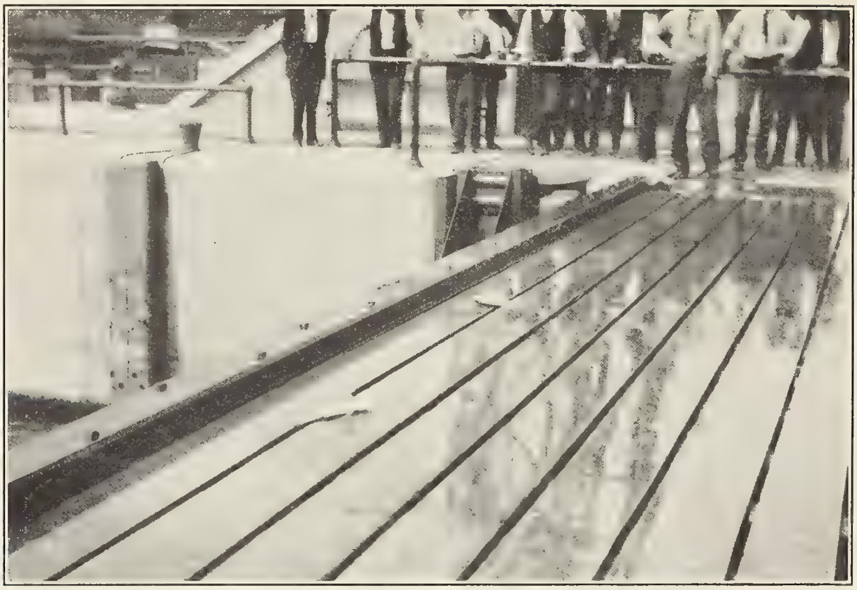

Figure 10.—The head gate of the lock has just been raised and several fish may be seen stranded on its top—a common occurrence

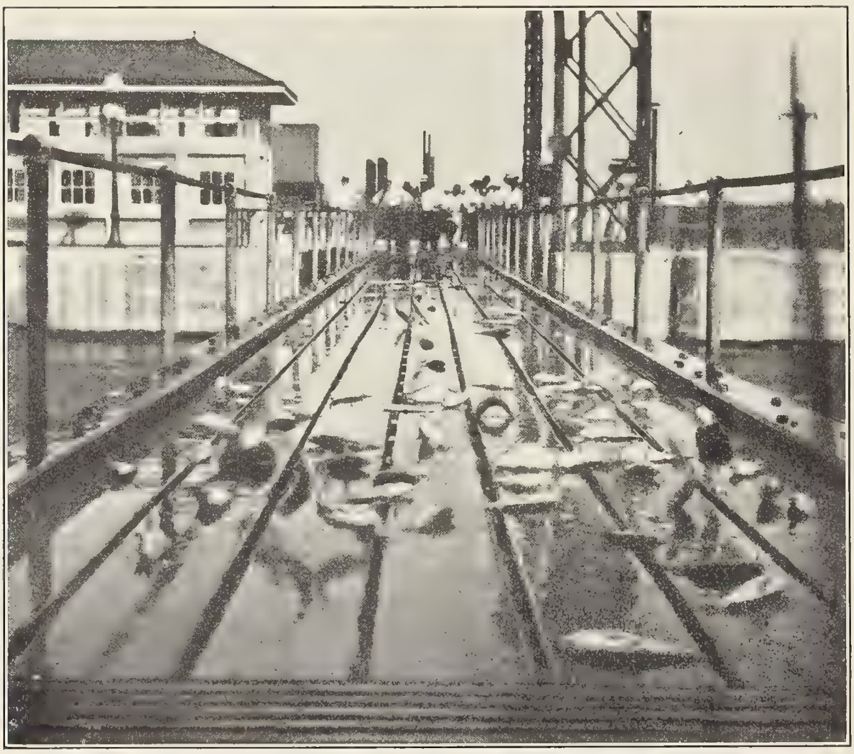

Figure 11.—An unusual catch of fish on the gate (in 1916), chiefly carp

the fact that shortly before the gate is lowered the disturbance incident to the filling of the lock causes the fish here to become very active. However, the taking of 46 Ohio shad, all except one from the lock side, indicates that a few individuals of this species find their way through the lock; from one to five a day were caught on various days from May 4 to July 11. The following may be added as to the species of which more than 25 were taken. The shortnose gar was very abundant about Keokuk and was found everywhere—river, lake, sloughs, and creeks. The same is true of the river quillback, which was, perhaps, the most abundant of all species in the locality that year. The spotted cat taken were nearly all small fish, evidently hatched the same year or the year before. The drum, like the gar, was very abundant, but particularly so in the vicinity of the power house and its accessories. Possibly some of the gar and drum taken were engaged in a migratory movement. The extremely small number taken of every sort of fish shows that there was no such massed movement over the upper gate as would have to occur to make the lock an effective fishway.

CAPTURE OF FISH ON THE UPPER GATE

Nearly or quite the only reason suggested for considering the lock to be a fishway was the fact that fish were often taken on the upper gate when it was raised. (Figs. 10 and 11.) Two stringers, 74 inches (188 centimeters) apart, run the length of the gate near its outer edges; the tops of them are 3⅜ inches (8.5 centimeters) above the surface of the gate. The surface of the gate between the stringers, being 110 feet long, has an area of about 678 square feet (63 square meters); this area consists of timbers laid with spaces between them, through which the water flows. The gate, therefore, is the equivalent of a huge shallow dip net, the stringers restraining the fish at the sides, and the length of the gate, as well as the walls, restraining them at the ends. The stringers are not the most effective possible restraint on fish, but they are high enough to hold some representatives of some species. On July 10, 1915, there occurred an opportunity to see how fish are thus held. The emergency or guard gate was up and held back the water of the lake, while below it the water level was that of the river. The regular upper gate was down and slightly submerged, but not deeply enough to have disappeared even in the muddy water of the Mississippi River. A German carp within the stringers was swimming back and forth along one of them, much like an animal in a zoological park, although by rising slightly it might have escaped.

During 1914, Mr. Huele, the lock master on duty from 8 a. m. to 4 p. m., made notes as to the species found on the gate. These notes contain the names of the same species that were taken commonly in 1915 and 1916 and show that very few fishes were taken when the water was unusually muddy.

During 1915 and 1916 a record was kept by the three lock masters of the number of fishes taken at all lockages. An effort was made at first to determine the species taken, but the gatemen (who reported to lock masters) found that it was impracticable, in the necessarily rapid work, to distinguish closely allied species. Observations made from time to time indicated that species were represented in about the same proportions as when the net was on the gate (see p. 100) except that the Ohio shad and the river herring were rarely, if ever, captured. Tables 2 and 3 were compiled from these special records of fish taken and the regular records of lockages made by the lock masters.

TABLE 2.—*Record of fish taken on upper gate of lock at Keokuk, Iowa, by weeks, 1915*

Week	Total lockages during week [1]	Gar	Shad, herring, and mooneye	Buffalo fish and quillback	German carp	Spotted catfish	Crappie	Sunfish	Pike perch	Striped bass	Fresh-water drum	Other species	Total fish during week
Feb. 28 to Mar. 6	1										8		8
Mar. 7 to 13	2			2							35		37
Mar. 14 to 20	9		1	4							31		36
Mar. 21 to 27	8								1		1		2
Mar. 28 to Apr. 3	21		1	2							8		11
Apr. 4 to 10	28			12				1			13		26
Apr. 11 to 17	27		1	11			3	2	1	1	12	1	32
Apr. 18 to 24	36	2	4	35	2	3	9	1	4	4	24	1	89
Apr. 25 to May 1	33	6	6	24	5	17	2		4	2	12	2	80
May 2 to 8	40	7	7	35	3	17	4	1	5		26	1	106
May 9 to 15	45	3	4	157	20	67	4	2	7	1	59	1	325
May 16 to 22	22	1	2	74	27	20	4		4	2	41	1	176
May 23 to 29	44	3	2	47	11	50		2	7	2	25	1	150
May 30 to June 5	42	2		5			2						9
June 6 to 12	51	3	1	11		5		1			25	1	47
June 13 to 19	43	11	19	112	6	33	3	1			31	2	218
June 20 to 26	54	8	10	53	4	24				1	33	1	134
June 27 to July 3	68	9	6	66	12	27	2	1			24		147
July 4 to 10	89	11	1	162	48	54	2				147	1	426
July 11 to 17	47	8	1	95	11	18					21		154
July 18 to 24	51	7	1	11		12			1		2		34
July 25 to 31	58	8	4	6		9	1				8		36
Aug. 1 to 7	58	2	1	2	1								6
Aug. 8 to 14	58	4	5	12	3	5						4	33
Aug. 15 to 21	54	6		45	6	14	1	1			61		134
Aug. 22 to 28	53	1	1	34	6	19	1	2		1	10		75
Aug. 29 to Sept. 4	42	2	1	104	29	29	3		1	1	94		264
Sept. 5 to 11	53	2	6	292	205	23			8	1	171		708
Sept. 12 to 18	37	1		8		7	2				8	3	29
Sept. 19 to 25	39	4		4	2	6			1		2		19
Sept. 26 to Oct. 2	45	1		6		13	2				11		33
Oct. 3 to 9	36			2					2		9		13
Oct. 10 to 16	40		1	2		2			7		39	3	54
Oct. 17 to 23	35		2		3	1			3		32	1	42
Oct. 24 to 30	33					2			3		18		23
Oct. 31 to Nov. 6	27			4							13		17
Nov. 7 to 13	19								2		3		5
Nov. 14 to 20	15								2		11		13
Nov. 21 to 27	19												0
Nov. 28 to Dec. 4	7			2							1		3
Total	1,489	112	88	1,441	404	477	45	15	63	16	1,069	24	3,754

[1] These totals of lockages do not include the 97 made as part of this investigation, because the lock masters did not record the fish taken at such lockages.

TABLE 3.—*Record of fish taken on upper gate of lock at Keokuk, Iowa, by weeks, 1916*

Week	Total lockages during week	Gar	Shad, herring, and mooneye	Buffalo fish and quillback	German carp	Spotted catfish	Crappie	Sunfish	Pike perch	Striped bass	Fresh-water drum	Other species	Total fish during week
Mar. 19 to 25	1			1							12		13
Mar. 26 to Apr. 1	5										31		31
Apr. 2 to 8	15			2				1			3		6
Apr. 9 to 15	15		1	17				1			2		21
Apr. 16 to 22	16		1	21							2		24
Apr. 23 to 29	26	3	4	27			4	1	3	2	5		49
Apr. 30 to May 6	26	5	3	36			2	2			7	1	56
May 7 to 13	24	16	10	15		1		1	1	1	3	1	49
May 14 to 20	16	8			1			1			1		11
May 21 to 27	21	17	4	3	1	6							31
May 28 to June 3	26	29	7		2	4						2	44
June 4 to 10	25	34	14	18	2	6						1	75
June 11 to 17	23	32	7	15	3	7							64
June 18 to 24	49	22	6	15	5	14					9	2	73
June 25 to July 1	35	31	3	25	12	14					3		88
July 2 to 8	38	44	18	35	185	5		1				3	291
July 9 to 15	48	34	13	54	664	8	2	2		1		3	781
July 16 to 22	36	34	1	14	498	16	3	27			4	3	600
July 23 to 29	32	10	1	13	202	18	1			1	7		253
July 30 to Aug. 5	46	37	21	15	2, 134	16	21	1	1	1	20	3	2, 270
Aug. 6 to 12	52	17	14	6	6, 666	6	11	2	1		23	3	6, 749
Aug. 13 to 19	41	14	20	1	2, 972	6	10	2	1		34		3, 060
Aug. 20 to 26	55	2	1		2, 129	4	12		1		11		2, 160
Aug. 27 to Sept. 2	47	3	2	4	1, 779	4	11				17		1, 820
Sept. 3 to 9	40	7	10	9	558	6	15	2			47		654
Sept. 10 to 16	29	2	10	5	150	5	9	1		1	32		215
Sept. 17 to 23	39	2	8	4	58	8	15		1	1	116		213
Sept. 24 to 30	26		2		28	6	4		2		38	1	81
Oct. 1 to 7	36		7	3	27	2	9		4		68		120
Oct. 8 to 14	28		3		13	3	3		4		29		55
Oct. 15 to 21	32	1	3	1	13	3	3				7		31
Oct. 22 to 28	41		1	1	2		2		1	1	4		12
Oct. 29 to Nov. 4	37		2	2	6		2		7		11		30
Nov. 5 to 11	40		7	5	24		3		4		12	1	56
Nov. 12 to 18	30						2		1	1			4
Nov. 19 to 25	35		2				1		5		2		10
Nov. 26 to Dec. 2	11		1	4									5
Dec. 3 to 9 [1]	11												
Dec. 10 to 16 [1]	1												
Total	1, 152	404	207	371	18, 134		145	45	37	10	560	24	20, 105

[1] No fish.

During 1915 the average catch per lift of the gate was 2½ fish. During 1916 the German carp was remarkably abundant in the vicinity of Keokuk, and this abundance was represented in the catch on the gate but at a later time than the spawning season. (Coker, 1930.) The average number of carp taken per lockage was 15.7; the average number of fish of all other species was 1.7. The records seem to show that the number of fish taken on the gate is no more than should be expected of such a device, particularly when it is recalled that the water in the lock is set into violent turmoil just before the gate is lowered. Evidently the lock transfers a few fish one way or the other, generally irrespective of the migratory movements of the fish. It is possible, however, that certain migratory movements are faintly reflected in the catch on the gate.

In 1926 lock masters Heule and Harrington informed the author that very few fish were now seen on the gate as compared with conditions in former years. Seven lockages were witnessed by the author or a member of his party on August 23, 1926, the total catch being 1 sheepshead, 5 fiddlers, and 4 sunfish, or 1.4 fish per lockage. While this seems a very low figure, it will be observed that it compares very closely with the record for 1916, excluding carp; furthermore, identically the same figure is obtained when the catches of the week of August 22 to 28, 1916, are averaged—75 fish in 52 lockages, or 1.4 fish per lockage.

One other feature of the lock must be considered in connection with the possible function of the lock as a fishway, and that is its location about one-half mile downstream from the dam proper, close to the Iowa shore and out of the main currents from the spillways and from the power house. Such a location, of course, is highly favorable to its use for purposes of navigation.

It is an obvious conclusion that fish engaged in an active upstream migration are guided by the direction of flow of the strong current. At Keokuk this would lead them past the lock and up toward the base of the dam from a region of generally slack water. There is nothing about the lock itself, with its large pool of still water, and the entrance to the lock apart from the main current to "suggest to the fish" that this is the best avenue of passage to the upper reaches of the river. It is not surprising that a large proportion of fishes taken in the lock are such as we associate with still waters or as are taken in shore nets—carp, drum, buffalo fishes, etc.

In regard to the lock, then, the evidence indicates that it does not function as an effective fishway. It is located apart from the main streams, and no current passes through it. Although it is frequented by a variety of species and many fish are stranded upon the upper gate when raised, the observation and experiments fail to reveal any evidence of a practical migration of fish through it. Systematic trials with a net closing the upper opening of the lock show that there is no considerable movement of fish there. The upper gate of the lock takes a few common fish because it operates like a dip net—with a very large surface but low sides. The number of fish caught thereon is what might be expected of such a device and is not indicative of any appreciable migratory movement, although it is possible that migratory movements of species are faintly reflected in the catch. Even if its location and structure were more favorable to its functioning as a passageway for fish, it could not do so effectively, because it is open above only for brief periods of a few minutes at a time, and the sum of all its open periods during the spring and early summer (when upstream migrations are expected) amounts to scarcely more than a single day.

CONCLUSIONS REGARDING THE DAM AS A BARRIER

We have seen that the dam must serve as a practically effective barrier to the upstream movements of fish. They can not pass up the spillways or even buffet the current below an open spillway. Undoubtedly they can not pass up through the turbine chambers. The lock, the only remaining means of passage, does not witness any distinct migratory movements through it. It is possible for fish to pass downward, perhaps through various passages, but especially over the spillways. We have no observations to indicate that any considerable number of fish pass from upper to lower river over the dam, and it is reasonable at least to suspect that fish engaged in a downstream movement would find in the large lake above the dam, with its deep and relatively still waters, the conditions ordinarily sought farther downstream, or that the slacking of the current in the lake would inhibit a further downstream migration. This would not of course, be the case if there were distinctly anadromous fishes (other than the Ohio shad—see Coker, 1930) in the Mississippi—that is, those that live in the sea or ascend rivers to spawn—or if certain species must avoid the cold waters of a northern climate.

The actual effect of the dam upon the several common species, as far as our data reveal it, will be treated in another place; but it remains in this connection to inquire into the general significance of the barrier in the light of observations of migrations of fishes at Keokuk.

SIGNIFICANCE OF THE BARRIER

TYPES OF MIGRATORY MOVEMENTS

The term "barrier," as applied to any fixture in the course of a stream, implies a necessity for some sort of movement of fishes from place to place. If any group of fishes were found to live continuously in the same place with no necessity or habit of removing therefrom, a structure of any kind placed above or below that place could not be termed a barrier for that group. No matter if the structure be impassable, it is not an obstruction to movement if there be no necessity or inclination for the fish to pass.

If another group of fishes is accustomed to range indiscriminately back and forth over an extended region, then a construction that checks these movements at a certain point becomes in a definite sense a barrier, but perhaps not a significant one.

If, again, some fishes are habituated to spend certain periods of their lives below a given point in a stream and other periods above that point, an impassable obstruction becomes a barrier of a significance that is greater or less according as the periodic migrations are essential for the continued existence and abundance of the species on one side or the other of the barrier.

The significance of the Keokuk Dam as a barrier depends, then, upon what species of fish may inhabit the Mississippi River at Keokuk in any season and what may be the migratory movements habitual or essential to those species. These are questions into which we must inquire as closely as possible.

The most familiar, because the most extreme and the most conspicuous, instances of a migratory tendency in fishes are those of the Atlantic shad, the alewives or river herring, and the salmons, all of which at certain definite seasons leave their accustomed waters to pass in definite migration up the courses of the rivers to spawning grounds that may be hundreds of miles from the point of departure in the sea. Such fishes are termed "anadromous," a word of Greek derivation meaning "uprunning." While none of the familiar species mentioned are found at Keokuk, it does not follow that there may not be other species there that are also of anadromous habit.

Another type of migratory habit equally pronounced, though less conspicuous and familiar, is just the reverse of the anadromous habit and is called "catadromous." This is manifested by the common eel, which spends the greater part of its life in rivers and lakes but which, on the approach of sexual maturity, abandons the fresh waters and journeys down to the sea to give rise to a new generation in the depths of the ocean. The young eels born in the sea find their way into the mouths of the rivers, which they ascend gradually and adopt as their home until they, in turn, must return to the sea to accomplish the ultimate end of their existence.

A third and very familiar form of migration is that characterizing the majority of the common fresh-water fishes, which at the time of spawning find their way into the shallower waters along the shores, in the outspreading water of spring floods, or in the upper portions of the smaller tributary streams. Very few of the common fishes are known to form nests or deposit eggs in the deeper waters of the rivers and lakes.

There are yet other manifestations of a migratory habit, which may be less regular or definite in character. Such are the movements governed by the search for food, the seeking of protection from extreme temperatures, the avoidance of enemies, or the perhaps involuntary drift with the current.

These, then, are the types of migratory movements that we must have in mind in our consideration of the fishes of the Mississippi as they may be affected by the dam

in question, and if our knowledge of the movements of fishes were complete it would be possible to answer in brief and definite terms the question of the significance of the dam as a barrier. That knowledge is as yet too incomplete, but, before listing and discussing the species of fish collected in the vicinity of Keokuk in the light of what we know of their movements (Coker, 1930), we may present in summary form the results of our inquiry as to whether or not there is evidence that any considerable migration of fish past Keokuk had existed and been checked by the dam and whether or not such interference with the movements of fish, if it exists, is of economic consequence.

EVIDENCE OF MIGRATION

On the whole, there has been discovered much less evidence of extensive migration passing or attempting to pass Keokuk than had been expected. The degree of abundance of fishes at Keokuk after the completion of the dam (see p. 94) indicated some sort of migration of paddlefish, river herring, Ohio shad, and possibly buffalo fishes, and subsequent observations have tended to confirm this indication.

Persistent watching for the gathering of fish about the dam, power house, and lock during 1915 and 1916, and evidence of various sorts accumulated in those years, made it appear that the structures also stopped some upstream movements of shortnose gar, carp, drum, and perhaps shovelnose sturgeon and three species of catfishes. Movements of the sauger may, perhaps, be checked in winter. We may well expect a decline in abundance of the eel above Keokuk. All of these species are of economic value, but the desirable characteristics of the gar are offset by other traits, and some reduction in its abundance will not be generally deplored. From what we know of the life histories of fishes it is believed that only the river herring and Ohio shad will have their spawning seriously interfered with, and this could be a matter of distinct economic importance in the case of the herring for reasons stated in the companion report. (Coker, 1930.) If the eel, one species of catfish, and possibly the paddlefish are substantially excluded from the upper river, there will result a loss of fishery products valued at a few thousand dollars annually. The checking of migratory movements by buffalo fishes and carp is not believed to be of economic significance, and probably the same is true in the case of the shovelnose sturgeon, two species of catfishes, the sauger, and the drum.

A very simple explanation may be offered for the upstream migratory tendency on the part of all of the species just mentioned (except the herring and Ohio shad) and doubtless for many other fishes.

It might be safely assumed that most fishes have periods of inactivity or of reduced activity. In aquaria it has been observed that such periods occur with yellow perch and black bass (Townsend, 1916); the carp hibernates (Hessel, 1878, p. 869), and observations elsewhere reported (Coker, 1930) indicate clearly that the same is true of the drum. Very probably they seek still places in which to spend their quiescent intervals, but nevertheless, they must be swept downward frequently, and even when not hibernating they must often be carried downstream.

If fish drift down with the current at any season, they must work upward or against the current at another, unless the upper parts of streams are to be entirely depleted. From this aspect it is a matter of indifference what the cause of the movement may be—necessity to find breeding grounds, to secure food, to encounter different temperatures, or something else. In such case an obstruction midway of a stream, which checks downward movement as well as upward migration, has no

material effect upon the abundance of fish above and below the obstruction, although local and seasonal distribution of fish may be modified somewhat. Stoppage of current, as in a pool, must check downward drift independently of a structural barrier.

In some cases these upward and downward movements extend for such a short distance that the species may exist above a dam placed close to the headwaters of a stream. However, we would expect to find fewer species above than below such a barrier, because those engaging in more extended migrations would not have a sufficiently extended range above.

Hankinson (1910) made an interesting study of the fishes in a small creek near Charleston, Ill. Seventeen species were collected, of which seven were common and permanent and three others were common at times. Even within the limits of this creek there appeared to be upward and downward movements, for during one spring a minnow (*Campostoma anomalum*) was abundant below but not above a temporary barrier until the barrier was washed out, and thereafter it was abundant farther up the stream. The author did not find any relation between temperature and the presence of fish (species not stated); the largest aggregation was seen on January 28, when, with the water a few degrees above freezing, examples of the minnow just mentioned were feeding. This is particularly interesting in its bearing on the hypothesis that has been suggested. If, as indicated by the observations of Hankinson, some species are active throughout the year, it is evident that they might maintain themselves in the headwaters of a stream without engaging in any considerable migratory movements. Further study may show that there is some relation between the extent to which river fish migrate and the extent to which they hibernate or æstivate, and that one habit is associated with the other in the case of species inhabiting running water.

Parenthetically, it should be stated that the hibernation or æstivation of fishes is probably less profound than that of mammals, the organs of locomotion, for instance, being used moderately. (Townsend, 1916.)

The migration of our inland fishes appears, for the most part, to be of the character that has been outlined. Obviously, movements of this sort might be checked at the middle of the range of a species without any result more serious than a limited seasonal gathering of fish below the dam and either a slight depletion of the upper river, by fish dropping down and being carried over the dam, or, where there is a lake above, the temporary accumulation of drifted fish above. If the barrier occurs near the limit of the range of a species that engages in this relatively slight sort of migration, that species might well be excluded from the upper side of the dam, and this probably has happened at Keokuk with the Fulton catfish.

Fishes that engage in extensive migrations to spawning grounds above the point where the dam is located would be affected more seriously because reproduction would be diminished or altogether prevented. Examples of this class are the Ohio shad and probably the river herring. The catadromous eel may be excluded from the upper river, thus having its range diminished though its spawning is not interfered with.

ALLEGED DIVERSION OF FISH UP THE DES MOINES RIVER

The Des Moines River enters the Mississippi about 3 miles below the dam, and the suggestion has naturally occurred to some that the dam would divert fish up this tributary. In September, 1913, shortly after the completion of the dam, reports reached the author that the Des Moines River at Ottumwa was filled with fish alleged to have been deflected up that river by the dam at Keokuk. He proceeded at

once to Ottumwa and Eldon to ascertain the facts more directly. Nineteen persons in all were interviewed, and the information gained served to throw rather more light upon human psychology than upon the actual effects of the dam. (See also, Coker, 1914, p. 24.) At Ottumwa, of nine persons engaged in fishing, eight said positively that there were no more fish than ordinarily, while one thought that there were more "Government shad" every year; five asserted that fishing was worse than usual; three of these fishermen said the dam was bound to have an effect, although it could not be seen. Of two persons who never fished, one had "heard" that there were more and one thought there "must" be more.[8]

At Eldon three fishermen reported the fishing poorer than last year, but one said there were more fish, although they did not catch more; two dealers said fish were distinctly less plentiful than last year; two nonfishermen said fish were more plentiful. Another person from Keosauqua said there were few fish this year at that place. Several persons at both places visited spoke of there being in evidence an unusual number of very small carp and channel catfish, not compensating, however, for the usually greater abundance of fish of commercial size. It was noteworthy that many of the fishermen suggested explanations for the unusual scarcity of commercial fish, attributing the cause to pollution or to gars.

It is certain that the rumors that led to the inquiries were based not upon facts but altogether upon expectation, and that the expectations were not realized in 1913. The expectation evidently was founded upon the common impression that there is a mass migration of fish in general up the stream courses, and that if this mass movement is checked in one stream it must be deflected into the nearest available tributary. Certainly the information gained does not offer substantiation for such an impression.

In July, 1916, Mr. Stringham spent two days at Ottumwa, Iowa, and found that there had been no remarkable abundance of fish in recent years; a few carp were then being caught on set lines, and it was said that catfish were taken occasionally. One or two fishermen believed that the Keokuk Dam diverted fish up the Des Moines River, but that they did not get above Bonaparte, Iowa, because of wastes from a gas plant at Ottumwa. One day was spent at Bonaparte, and careful inquiries were made of the one man who depended largely on fishing for a livelihood and the three others who did considerable fishing. They testified that the gar was the only fish taken in unusual numbers and that fishing was better when there had been a dam at the location. The dam referred to was washed out about 1903 (Lincoln, 1904, p. 11), 10 years before the completion of the Keokuk Dam. However, it was definitely learned at Keokuk in October, 1915, that commercial fishermen from that place were then making some large catches of spotted catfish on the lower Des Moines River. Inquiry of three of the older fishermen showed that the Des Moines had long been a good place to catch this species, particularly in autumn, and the literature shows that the fish was very common many years before the Keokuk Dam was built. (Jordan and Meek, 1885, p. 2; Call, 1892, p. 45.) It is possible that the runs of spotted cat in the Des Moines River in 1913 and 1915 may have been increased by fish from the Mississippi, which, but for having encountered an obstruction at Keokuk, would have continued up the main stream; but there is no evidence to that effect.

[8] A Mr. Bryant at Ottumwa told of the capture of a single specimen of paddlefish in the Des Moines River at Ottumwa in 1911 (before the dam was built). The fish was unknown locally. There is, I believe, no other record of the capture of this species in that river.

INJURING AND DESTRUCTION OF FISH

EXTENT AND CHARACTER OF INJURY

From the time the plant was completed there have been complaints by the fishermen that fish were being maimed and killed. These injuries are variously attributed to the turbines and rock piles at the base of the dam; some think they occur while fish are trying to ascend and others while they are moving downstream. Although no conclusion has been arrived at, the evidence is presented in full so as to be readily available for future investigation.

The observations by Surber (Coker, 1914, p. 15), and by Stringham during 1915 and the first half of 1916 failed to throw light upon the matter, though a few dead and injured fish were noted.

In August, 1914, the author observed several examples of the paddlefish taken in a floating gill net in swift water below the dam, the snouts of which had been broken off entirely. During June and July, 1915, there were usually some dead fish floating in an eddy at the south end of the finished half of the power house, and in the course of the same months reports from four independent sources told of dead catfish floating down the river.

On May 26, 1916, a goujon, 84 centimeters (33 inches) over all, was found floating past the lock with the left half of the head to the shoulder girdle cut off; the fish was fresh, and the flesh was used by one of the men working at the lock. A German carp about 1 meter long was found in the eddy below the power house on June 9 with a gash near the dorsal edge just behind the collar bone. Another fish of about the same size and probably the same species was seen on July 15 floating down the tailrace with its head cut off to the shoulder girdle. One or two more large and some smaller fish were seen floating, but the character of their injuries was not ascertained.

From the beginning the complaints had centered largely on the paddlefish, but very few representatives of this species were taken during 1915 or the first half of 1916. On July 31, of the latter year one was picked up off Main Street in Keokuk, having the bill or snout broken off and the operculum hanging loose. Up to August 23 one other example (a very small one) was seen at Keokuk, and this likewise had the snout broken. On alternate days, beginning August 23 and ending August 31, seine hauls were witnessed in which 53 paddlefish were taken, being more than were seen in the course of the rest of two seasons' work. Of these 36 fish, constituting 66 per cent, had the snouts broken. Included in these 36 were about half a dozen with the bones cracked but the snout not lost nor bent, and approximately as many with part of the snout gone. The usual type of injury was a fairly clean cut, there being no general mashing of the snout. The body was otherwise unhurt.

With a view to learning whether paddlefish suffer this way in other localities some inquiries were made. On August 24, 1916, Earl Bauter, then at Montrose, Iowa, mentioned that they had taken one on the Illinois River the preceding fall with its snout broken. In reply to a question he said that they had caught altogether 75 to 100, and the rest were sound; most of them were caught in a seine and a few in hoop or fyke nets. Of half a dozen large ones taken in Keokuk Lake that summer, all were uninjured. Dr. George Wagner, who in 1904 examined about 1,500 at Lake Pepin (Wagner, 1908), wrote on September 13, 1916, that all were taken in seines, and that while he kept no record of injuries he is very sure that none of them showed any sign of broken bones. On September 18, 1916, Austin F. Shira, director of the Fisheries Biological Station, Fairport, Iowa, said he had seen about 500 taken in

seines at Lake Pepin but none with the snouts broken. On October 1, 1916, Franz Schrader wrote that he examined about 40 captured by seine at Lake Pepin that year. About half of these were examined closely for microscopic parasites; some had slight abrasions, but none had any serious injuries. Stockard (1907) evidently examined many fish during two springs in Louisiana, but the number is not indicated; he found three whose snouts had been broken and the wound healed over.

It will be noted that the injuries received about Keokuk were almost exclusively to the heads of the fishes. To secure testimony as to the part of the body that was usually hurt, the question was put to a number of fishermen and dealers, care being taken to make it general in form so as not to indicate the answer expected. The dates of inquiry, names of men, residences, and the substance of the replies are as follows:

August 29, 1916

Ed. McGee, West Keokuk. Spoonbill (paddlefish) injured only on snout; buffalofish sometimes have scales off and are sometimes hurt on mouth.

September 4, 1916

Joe McAdams, Keokuk. Generally on head or behind shoulder girdle; hardly ever elsewhere.

William Stanton and Mr. Wilson, Keokuk. Mostly on head, but occasionally a hole is punched in them anywhere.

Trumer Jackson, Warsaw. Spoonbill and carp, mostly on head, some nearly cut in two. No injury to any other part noticed.

Luthur McAdams, Alexandria. On head only.

September 15, 1916

Jack Job, Canton. Mostly on head, sometimes on tail.

Joseph Winkler, Canton. No injured fish found.

STRUCTURES CONSIDERED

The rock piles at the base of the dam and the turbines are the two instrumentalities that had been suspected of being responsible for injuries to fish. The rock piles have been mentioned in connection with the description of the dam on page 93. (See, also, fig. 12.) During the spring of 1915 the power company was making some observations on the turbines, and this gave an opportunity to inspect the structures in question; the descent to the turbine was made on April 1. If a fish should get to the head bay and through the screens or grating as already suggested (p. 97), it would then be in the intake or scroll chamber; this is normally full of water even when not in operation. As shown in Figure 13 it is dry. The flow of water is regulated by opening or closing the gates or vanes, which appear in the upper middle of the illustration behind slender columns; they open and close by partially revolving on their long axes. These vanes are the first obstacle that a fish would meet after passing the screens. On the day of observation the vanes stood with openings between them about 9 inches (23 centimeters) wide. When a unit is generating electricity these are slightly but constantly oscillating, so as to regulate precisely the pressure on the turbine; but the size of the opening remains substantially the same as when it was measured, except that one unit, used for electricity sold locally, has a smaller opening, being, about 5 inches wide, according to information supplied by the power company.

Inside the vanes is the turbine, more commonly called "wheel." Between the vanes and the blades or buckets of the wheel there is a large space. The wheels are

Figure 12.—Looking eastward over the dam in July, 1913. Exposed rocks may be seen below the spillways. (This photograph was taken soon after the dam was completed)

Figure 13.—Intake or scroll chamber leading to one of the turbines. Note the man in the shadow in the center of the picture

Figure 14.—Rotor or wheel of a turbine in process of installation

of two types. The type shown in Figure 14 gives a clearance of about 0.5 to 0.8 foot (15 to 23 centimeters) less than the other, but still large enough for any fish of the locality. It should be understood that the water passes smoothly and without commotion through the turbines, so that a fish passing with the water would move rapidly but without being subject to any violent churning action.

The wheel itself was examined as closely as possible. The blades or buckets appeared to come closest together at the top of the inner edge, where the aperture, as estimated, is 6 to 7 inches (15 to 18 centimeters) wide; this widens downward to about 10 or 12 inches; below is the river.

After passing the screens in the head bay, a fish would nowhere find a narrower passage than the screens afford, except in one unit, where the vanes stand about 5 inches apart. Probably a fish is trapped here occasionally, but it seems doubtful whether many fish go down through the turbines (p. 97); and the percentage, small enough to pass the 6-inch screen but too big for the 5-inch vanes, that chances to enter this particular unit must be negligible.

EXPERIMENTS

In an effort to learn whether fish are hurt at the base of the dam or elsewhere, Stringham allowed several fish to pass over the dam and others to go through turbine chambers. Three attempts in May and June, 1916, with paddlefish, goujon, and carp, respectively, were made by tying a line to the fish and attempting to draw it back, but in spite of modifications of method each time the three fish were lost because the line broke. The goujon was seen swimming before the line broke.

On June 18 a carp 53 centimeters (21 inches) long and weighing 2 kilos (4½ pounds) was dropped on the crest of the water of operative spillway 104, with a long line tied through its caudal peduncle, played out, and drawn back at another part of the dam; it was entirely uninjured and lively. On August 2 a carp 51 centimeters (20 inches) long and weighing 1.5 kilos (3⅓ pounds) was similarly dropped through spillway 105, a twisted cotton line (No. 90 or thereabouts) 116 meters (380 feet) long being used. The fish was drawn back alive but with scales scratched off each side of the back before the dorsal fin, the left opercle broken into four pieces, and the shoulder girdle partly severed from the body.

On August 3 two carp, the smaller 56 centimeters (22 inches) long and weighing 2 kilos (4½ pounds) and the larger 81 centimeters (32 inches) long but not weighed, were fastened to ½-gallon buoys by lines each about 3 meters long, tied through the lower lips. They were dropped through spillway 106. The smaller was picked up below entirely uninjured. The larger was slightly scratched on the right opercle, and there was a little blood on each side under the base of the dorsal fin, but there was no abrasion.

On August 24 three paddlefish, measuring 63 to 84 centimeters (25, 28, and 33 inches), respectively, were dropped through spillway 42, similarly attached to buoys but with the line tied through the caudal peduncle. One became fast among the rocks but later floated free. The smallest was picked up dead but bore no marks. The other was uninjured, though there was a slight scratch at the base of the caudal fin, which may have been overlooked before the fish was dropped in.

On August 27 several paddlefish, with pieces of cork from a life preserver tied to their snouts, were dropped into a whirlpool in the head bay of the power house, inside the screens; and, after passing through a turbine, one was picked up in the

river below. On the first one dropped into the head bay, too much cork had been tied and it did not submerge. Two others disappeared, and it is not known whether they went down. Two more evidently went down because the corks were found below. A sixth fish was put through and picked up below entirely uninjured and lively. This one was 72 centimeters (28½ inches) over all, and the piece of cork tied to its snout was 7½ by 4½ by 2½ centimeters; it had been dropped into the head bay above unit 8 and carried down by a strong whirlpool.

On August 29 two more paddlefish of about the same size and with slightly larger pieces of cork were put through in the same manner and picked up swimming and uninjured.

With little hope of success, two attempts were made to test whether fish are hurt while trying to ascend the draft tubes. Paddlefish were staked out in the tailrace by means of a long line tied to the tail; but the line repeatedly became entangled in something at the bottom of the tailrace, and the effort was abandoned.

DISCUSSION OF EVIDENCE AND CONCLUSION

The net results of the experimentation and observation are negative. The fishes dropped over the dam and put through the turbines escaped remarkably well, considering how they were hampered, particularly as the worst-looking places were selected purposely. Furthermore, the injuries received were to various parts of the bodies instead of being confined to the heads. It seems entirely possible that fish should ascend the draft tubes to the turbines, the velocity of the water being only about 9 miles immediately under the wheel and considerably less than 3 miles at the outlet. (Mississippi River Power Co., 1913, p. 32.) But, though the wheels move at a considerable velocity, the portions of them that would strike an ascending fish are broadly rounded, and it seems improbable that the injuries received could be inflicted by such a surface. In spite of these negative indications it is possible that further work would show that fish are sometimes hurt in one of the ways suggested. Paddlefish, at least, are damaged in substantial numbers, and it is desirable that the cause be ascertained. There remains the possibility that the fish are injured in attempting to pass between some of the old pilings that, for a long time, at least, remained submerged about the raceway below the power house. If, while swimming abreast of the current, a fish should attempt to pass between two closely approximated piles, it is conceivable that the force of the current against the body of the fish would wrench the bill off as readily as one could break the bill by inserting it between two posts and moving the fish sharply to one side.

EFFECTS OF THE DAM UPON CONDITIONS IN THE RIVER BELOW

BOTTOM CONDITIONS

The bottom material at and near Keokuk, below the site of the dam, as shown by Chart No. 136 of the Mississippi River Commission, was rock and sand with a little gravel and clay near the banks. These conditions were not changed by the dam, except that some sand may have been washed out right at its base. Places reported to have a bottom of mud were found by dredging (in April and May, 1916) to have sand, with occasionally molluscan remains and sometimes clay pellets. The changes in the character of bottoms above the dam must be pronounced and significant, but opportunity has not occurred for the investigation of such conditions. Before the dam was built the bottom in the rapids was described by Clark (1911) as "solid rock bottom all the way across." He said, furthermore:

The waters at Keokuk can not accurately be called turbulent. They are not hurled over hidden boulders and irregular rocks with the speed of a Niagara. The river has much the same velocity and presents the smooth appearance of water running down an inclined surface.

While under such conditions the bottom might be expected to be swept fairly clean, there were enough loose rocks and gravel to support very abundant fresh-water mussels. No doubt under lake conditions there must occur a gradual accumulation of silt over the former bottom of the rapids. (See remarks on silting in section entitled "Fresh-water mussels" in Coker, 1930.

ICE

One striking change has occurred in river conditions. For a distance below the plant the river no longer freezes over, because the obstruction breaks up the ice. Sheet ice forms in the coves, and a couple of miles south it extends from the banks well out into the river. At Warsaw (5 miles south of the dam), in 1915, the frozen area extended nearly to the channel from each shore; but, according to information supplied by the fishermen, the river was not entirely frozen for another mile down. The next year the river probably did not freeze over anywhere south of Keokuk, although some informants asserted that it froze entirely across for a short distance somewhere between Canton, Mo., and Warsaw, Ill. Local informants report conditions in 1916–17 that were similar to those of 1914–15. Prior to the construction of the dam the river usually froze sufficiently so that teams could be driven across along the whole region from Canton northward and for some distance southward.

The open condition of the river has been a boon to fishermen, facilitating operations in the winter. Men who used fyke nets reported that anchor ice formed on their nets and hampered them. The formation of such ice at the bottom of a river, where the current is rapid and the surface open, is a phenomenon that has long been known but is not very well understood. (Barnes, 1906, Ch. VII.)

OXYGEN CONTENT

No observations have been made on the extent to which the water is oxygenated by the Keokuk Dam, but this must be great. The early conditions in the lake above, with decaying vegetation, active animal life, and deficient plant life, may have caused diminution in the percentage of oxygen below the average for the river. So far as the lower river is concerned, this loss probably is fully compensated for by the dam. On the Illinois River, Forbes and Richardson (1913, pp. 542 and 549) found that polluted water had its dissolved oxygen substantially restored and its carbon dioxid diminished by falling over a 10-foot dam. The authors added that the difference in oxygen doubtless had its effect upon the abundance of fishes, but that the fish population below the dam was small as far as indicated by limited observations. The present conditions on the lake are likely to be followed by others that will tend to give a higher percentage of oxygen to the water. Since the conditions have not been investigated, they can be referred to here only as suggestive of a significant factor in the influence of the dam upon fish life in the river.

FLUCTUATION OF RIVER STAGE

To determine as nearly as possible the effect of the dam in respect to increased or lessened stability of river stage below Keokuk, the reports of the United States Weather Bureau (Frankenfield, 1911, p. 235; Henry, 1913, p. 219; Henry, 1915, p. 231; Henry, 1916, p. 89) and later reports have been examined, and, from the daily stages given therein, certain computations have been made, and these are embodied

in Table 3. Although there are differences each year, the records prior to 1913 cover approximately the months of March to December, inclusive, but all observations given for those years are included in the computations. The stages of 1914 and subsequent years are recorded complete, but the computations are based on records from March to December, inclusive.

TABLE 4.—*Oscillations of river stage, in feet, at Keokuk, Iowa, 1910–1912 and 1914–1919 (including, for comparison, yearly fluctuation at Davenport, Iowa)*

Year	Davenport, Iowa	Keokuk, Iowa									
	Difference between highest and lowest in year	Difference between highest and lowest in year	Difference between first of month and first of month following, maximum and minimum			Difference between Sunday and following Sunday, maximum and minimum			Difference between morning and following morning, maximum and minimum		
			Least	Most	Average	Least	Most	Average	Least	Most	Average
1910	7.8	12.0	0.9	8.4	2.86		2.9	0.63		3.0	0.16
1911	10.6	12.3	1.8	11.8	4.76		10.4	1.33		2.9	.29
1912	11.3	17.7	.1	5.8	[1] 1.7		5.6	1.31		6.4	.31
Average	9.9	14	1.33	10.23	3.98		6.30	1.07		4.1	.25
1914	8.9	13.3	1.4	7	3.97		5.8	1.10		3.6	.33
1915	8.1	15	2.7	10.2	6.19		5.2	1.81		5.2	.43
1916	13.9	17.6	.2	8.6	2.75		9	1.30		4.87	.37
Average	10.3	15.3	1.43	8.6	4.3		6.67	1.40		4.56	.377
1917	11.1	16.6	.1	12.8	2.66	0.5	5.9	1.36		6.5	.33
1918	9.3	16.6	.3	7.2	3.32		4.5	1.01		2.8	.36
1919	13.3	18.1	.4	8.7	3.15	.3	8.7	1.95		4	.43
Average	11.2	17.1	.27	9.57	3.04	.27	6.37	1.44		4.43	.373

[1] 9 months.

It will be observed that the average annual fluctuation of river stage at Keokuk was more marked during the 3-year period (1914–1916) immediately following the construction of the dam (15.3 feet) than during the 3-year period (1910–1912) preceding its construction (14 feet), and even more so during a following 3-year period (1917–1919)—17.1 feet. It was urged by the power company that the differences indicated by these figures were due to climatic causes rather than the dam. They claimed that the daily combined flow of water through the power house and over the dam was equal to the natural flow that would occur here, except that they occasionally raised or lowered the lake very gradually and except that the wind made a slight difference. According to their computations the variation resulting from the raising or lowering of the lake amounted to only two or three-tenths of a foot a day.[9] Whether or not this would make enough difference to account for the instability shown by the foregoing table may be doubted.

Certainly, some corroboration of the view of the power company is derivable from a comparison of the fluctuations of stage at Davenport, Iowa, during corresponding periods. Davenport is far enough above the dam (120 miles by river) to be beyond the possibility of effect from the dam. Nevertheless, the fluctuations during corresponding 3-year periods have displayed a somewhat similar history. The average yearly range for the period 1910–1912 was 9.9; for the period 1914–1916 it was 10.3; and for the period 1917 to 1919 it was 11.2. The years of greatest fluctuation were the same as for Keokuk, namely, 1912, 1916, and 1919. Evidently,

[9] Based upon verbal statements of an officer of the company to Emerson Stringham in 1916.

then, either climatic or other conditions in that part of the Mississippi Basin above Davenport have caused greater fluctuations of river stage in years subsequent to the construction of the dam than in years immediately preceding. The facts coincide with the suggestion made on page 88, above, that under modern conditions fluctuations of river level are tending to become sharper and more extreme. There seems to be further support for that suggestion in information communicated to the author by the Mississippi River Commission in a letter of April 4, 1927, referring primarily to another matter:

> The records of this office cover only 15 low waters at Keokuk, 10 of which were below zero. The lowest was 2.8 feet below zero (481.86 feet above Memphis datum) on December 18, 1922.

The creation of a constantly higher level for some miles northward of Keokuk may have reduced the capacity of this portion of the river to take up floods; in other words, the floods become largely concentrated at Keokuk. Conversely, it is necessary, when the river is falling, to hold back water to maintain the constant level of the lake, and this, of course, occasions a more rapid fall below. Earnest efforts, it is believed, are being made by the company to maintain as stable conditions as possible below, and their records showed improvement in 1916. These efforts are made with the object of avoiding the infliction of damage to steamboats, but the results are of advantage to the fishery, for violent and excessive changes would result in the stranding of fishes, as actually occurred at the beginning through inexperience. (Coker, 1914, p. 10.)

LAKE KEOKUK

CREATION OF A RIVER LAKE

The Keokuk Dam has changed the Des Moines Rapids and a part of the river above them into a large area of relatively still water. (Figs. 2 and 17.) From the biological as well as from some other standpoints this is a matter of great interest. For this body of water the name Lake Cooper was commonly used and will be found in the literature, but the United States Geographic Board (1916) has decided upon the name "Keokuk Lake."

Stockard (1907, p. 758) remarks upon waters of this intermediate character as follows:

> Other such lakes still retain a direct connection with the river and are termed by the fishermen "river lakes." In these there is a current, which often becomes very strong during the spring freshets, when the water of the Mississippi River rises.

The present author (Coker, 1914, p. 9, footnote) defined the term as meaning "such a body of relatively still water as would ordinarily be called a lake, which is yet intimately connected with a river, either as interpolated in the course of the river or as an arm of a river."

It is scarcely necessary to add that there exist waters intermediate between river-lakes and rivers, on the one hand, and between river-lakes and lakes on the other. The distinction is one of degree but none the less valuable for that reason.

The biological conditions of the lake in 1914 were studied by A. A. Doolittle, and a summary of his observations is presented in another section of this report (p. 118). A more exhaustive and continued investigation of the lake would have been of great practical importance, but, unfortunately, it could not be arranged to continue or to report upon the survey until the observations of Doctor Galtsoff were made in 1921 (p. 119). It is necessary for our present purpose, before discussing

the several species of fish, to present a general account of the physical and biological conditions of the lake based primarily upon observations of Mr. Stringham.

AREA

The effects of the dam are said to extend as far as Oquawka, Ill., 41 miles (66 kilometers) northeastward from Keokuk and 54 miles (87 kilometers) along the course of the lake and river; but the influence as far away as this is scarcely perceptible, and the upper end of the lake may, for convenience, be taken as at Burlington, Iowa, 31 miles (50 kilometers) northeastward from Keokuk and 42 miles (68 kilometers) along the course of the lake (fig. 15). The general form between these two points is that of a drawn-out letter S or a compound curve, the outer edges of the curves being at Dallas City, Ill., and just north of Montrose, Iowa, respectively. The width varies from about ½ to 2½ miles (0.8 to 4 kilometers), as appears from a map prepared by the power company in 1913 or 1914. Subsequent raising of the water level may have increased this maximum width, and even on the map the width is greater where slender fingerlike projections extend out from the general border of the lake.

The area of the lake, as roughly determined by applying a planimeter to the same map, was about 53.3 square miles (138 square kilometers), but this map does not include all backwaters. The records of the power company show that from the greatest level in 1914 (occurring January 29) to the greatest level in 1916 prior to September (occurring January 15) an additional 3.6 square miles (9.3 square kilometers) was overflowed. Part of this additional overflow would be above Burlington, which has been assumed to be, practically speaking, the upper end of the lake. Including all lateral backwaters, the total area of the lake in 1916 was probably in the neighborhood of 60 square miles (about 150 square kilometers). According to information supplied by the power company, the lake was to be raised an additional foot, and the total area would then be nearly 70 square miles. Of course, there has been a large increase in volume of impounded water, and, by calculations made at the office of the company in June, 1917, this would amount to somewhere in the neighborhood of 14,000 million cubic feet, when the lake had been raised to the stage of 525 feet, Memphis datum. Unfortunately, from the viewpoint of the fisheries, the area of the lake has now been reduced substantially by the construction of levees and the reclamation of submerged lands for use in agriculture. The principal drainage district (covering the Green Bay region and lying between Fort Madison and the Skunk River) was drained during the winter of 1918–19; this reduced the area of the lake by 10 to 15 square miles. Under present conditions the area of the lake varies between 58 and 64 square miles, depending upon the stage of the water.

DEPTH

The water depths for this region as it was are shown on Charts Nos. 136 to 140 of the survey made by the Mississippi River Commission in 1891. These soundings were made at low stages of the river, those for the rapids (Keokuk to Montrose, Iowa) being made while the river was at 1.5 feet on the Keokuk gage, or at 486 Memphis datum. The greatest depth on the rapids was 15 feet (4.6 meters), and the depth along most of the channel was about 6 or 7 feet (about 2 meters). From Montrose north to Burlington there were some soundings of 26 feet (7.9 meters), but the depth of the channel did not average over 12 to 15 feet (3.7 to 4.6 meters).

FIGURE 15.—Lake Keokuk and the adjacent parts of the Mississippi River. (Above dam areas formerly submerged, bu
formerly above water but now submerged and relatively shallow are indicated by close stippling. Below dam shallow
1901, indicated thus, ...; 1904, thus, — — — —; old wing dams indicated ———. Reduced from blue print furni

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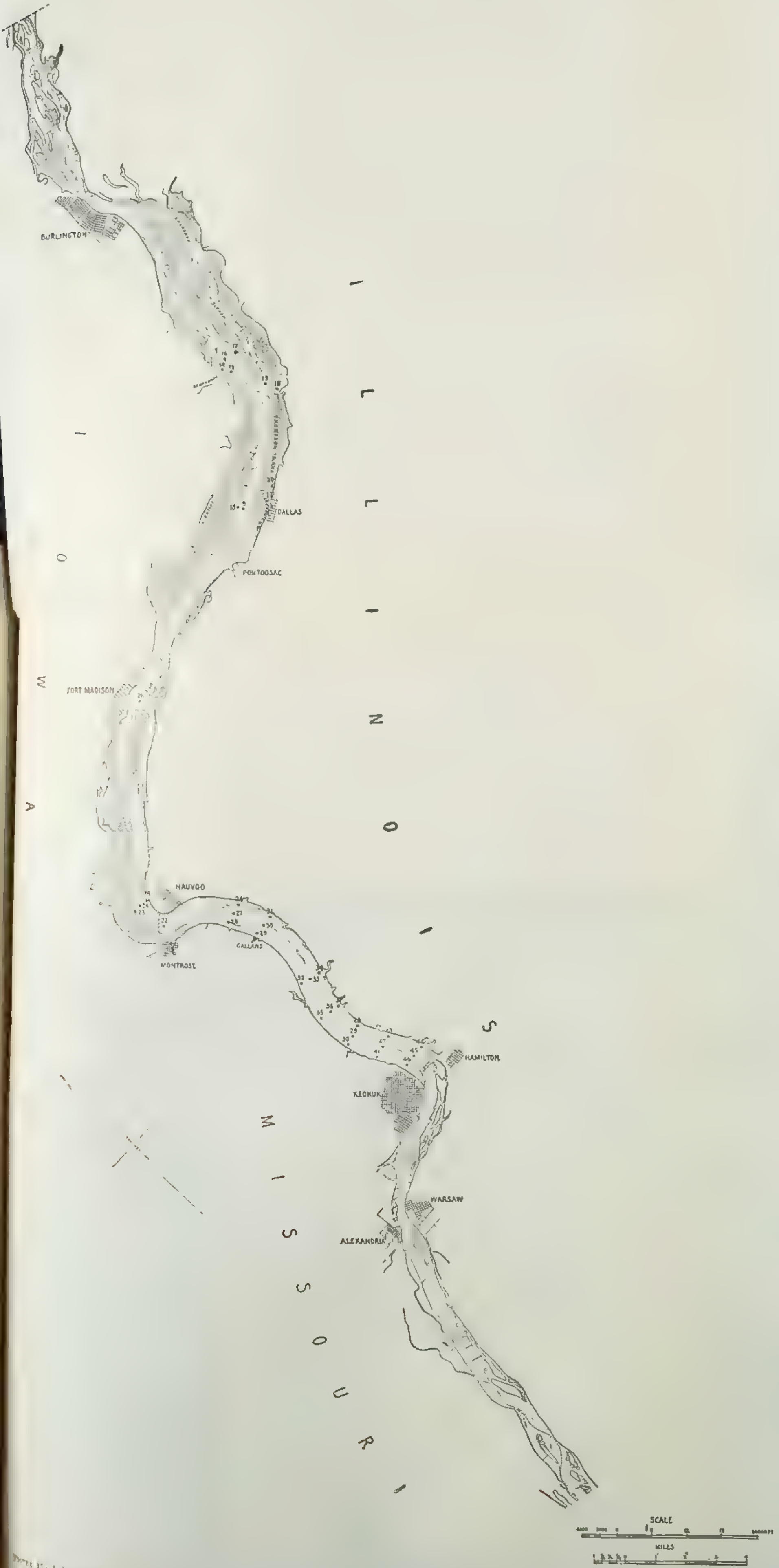

[illegible] —Lake Keokuk and the adjacent parts of the Mississippi River (Above dam areas formerly submerged, but shallow, are defined by dotted outlines, are as [illegible] above water but now submerged and relatively shallow are indicated by close stippling. Below dam shallow areas are indicated by stippling Boat channels, indicated thus, .; 1904, thus, — — — —; old wing dams indicated ———. Reduced from blue print furnished by Chief of Engineers, War Department.)

[illegible]

(Face p. 54)

The surface level of the new lake at Keokuk, according to the records of the power company, did not fall below 520.8 Memphis datum during 1916, or nearly 35 feet (10½ meters) higher than at the time of taking the soundings just mentioned. This would give a depth of 40 to 50 feet (12 to 15 meters) on the old rapids, were there no filling in by sediment. On July 23, 1916, soundings were made at three points in the fore bay just above the lock. These showed depths of 36½ to 40 feet (11 to 12 meters); on this day the lake stage at the lock was 523 feet, Memphis datum. The place where these soundings were made is below the dam and power house, and evidently there has been little filling in here.

On July 4, 1917, when the lake stage, according to the lock master's record, was 523.5, soundings were made at intervals of 100 meters, first crossing the lake beginning at the point of the power-house portion of the ice fenders and proceeding to the Illinois shore, and then recrossing the lake at a distance of ½ to 1 kilometer above the first line. The depth to within 300 meters from the banks varied from 7.3 to 11.1 meters (24 to 36½ feet), being for the most part between 9 and 10 meters, deeper above the power house and shallower near the Illinois side.

For much of the distance from Keokuk to Burlington, on the Iowa bank, the bottom rises rather abruptly; but there are large areas of shallow water, particularly in the vicinity of Fort Madison and below. On the Illinois side the bottom slopes up more gradually at most points.

TURBIDITY AND TEMPERATURE

There are probably no existing data as to the turbidity of the old river where Keokuk Lake now exists. The lessened velocity of the water would tend to reduce this, because of settling, but the accumuated silt on the bottom may be stirred up from time to time by irregular movements of the water.

In the fore bay, where the water is rushing to the power house, turbidity was observed on 71 days during 1915—from April 12 to August 13. A rectangular piece of wood with an area of about 1 square centimeter (16 square inches), painted white, disappeared at depths of 9 to 47 centimeters (3½ to 18 inches), the average being 21½ centimeters (8½ inches). As a substantial part of the matter carried in suspension probably has been deposited before the water gets to the fore bay, it is reasonable to suppose that the turbidity of the lake would usually be greater toward Burlington.

Water temperature was observed at the same place in the fore bay. Observations were made on 75 days in 1915, beginning April 9 and ending August 14. During this period the temperature ranged from 50½° to 79° F. (11° to 26° C.). The season of 1915 was cooler than that of 1916; on July 14 of the latter year, at 11 a. m., a temperature of 86½° F. (30° C.) was recorded just above Montrose, Iowa, where the lake is shallow. While the depth of Keokuk Lake is not sufficient to justify expectation of any considerable difference between bottom and surface temperatures, Doolittle (MS.), in 1914, found that the bottom of the lake at Keokuk always registered 2° F. lower than the surface. The bottom temperature is probably about the same as in the old river, or possibly a little cooler in midsummer and fall; the surface may be a little warmer, as the water from the north now remains here longer than it did in the day of the rapids.

VELOCITY OF CURRENT

The rate of the current on the old rapids is given in a report to the Secretary of War (Hains, 1867, p. 277), as follows: "Its mean surface velocity is 2.88 feet per second, and its mean velocity deduced therefrom is 2.304 feet per second" (a little more than 1½ miles per hour). A study of the former current at Burlington was made with much refinement by Mackenzie (1884) in the month of October. He found it to vary from 1.2 feet per second (0.82 m. p. h.) on October 7 at a depth of 16 feet to 2.9 feet per second (1.98 m. p. h.) on October 14 at a depth of 1.7 feet. Doolittle (MS.), in the summer of 1914, made three observations each near Keokuk and Nauvoo and two near Burlington; these were presumably at or near the surface. Table 7, based upon these records, shows roughly the difference between the old and the new conditions. At Burlington the current has been scarcely checked; right above the dam it has been almost stopped. The velocity on the old rapids must have been much greater at times than these figures show. In 1910 (Frankenfield, 1911, p. 234) the stage at Galland rose 3.9 feet (1.2 meters) from December 21 to 22 and had fallen 4.3 feet (1.3 meters) the next day. On the second of these two days the velocity at and below Galland must have been very great.

TABLE 5.—*Velocity of former river, in miles per hour, compared with present lake*

Place	Old river	Present lake
Old rapids, now lower end of lake	1.58	0.0–0.4
Nauvoo, Ill., 12 miles north of dam		.64–1.2
Burlington, Iowa, now the upper end of lake	0.82–2.0	1.13–1.8

BOTTOM MATERIAL

The bed of the old rapids was described by Hains (1867, p. 277) as "a broad, smooth rock, seamed by a narrow, crooked channel, or in some places several of them, alternately widening and narrowing, shoaling and deepening * * *. The rapids are, therefore, not broken and noisy, but, the descent being gradual, the water flows over its bed in a broad, smooth, unbroken sheet, with nothing but the faintest ripples on its surface * * *." Keys (1895, p. 316) states that the bed of the rapids was chert (a quartz similar to feldspar) lying at the top of the Burlington limestone. Charts Nos. 136 to 140 of the survey by the Mississippi River Commission show patches of sand and gravel at the upper end of the rapids; from here to Burlington the bottom was nearly all sand, with some rock and gravel and scarcely any mud. Writing of the conditions in 1914, Doolittle (MS.) states that the bottom of the lake where sounded or dragged was a fine bluish-gray mud, but that a sand bar had formed off Nauvoo, Ill. On July 4, 1917, many soundings were made within about one-half mile above the dam, and only mud was found, except close to the banks. Reference may be made here to the remarks concerning the silting in of the area of the former rapids, made in the section of the companion report (Coker, 1930) entitled "Fresh-water mussels."

PLANKTON OF THE LAKE IN 1914

In the second season of the lake, Dr. A. A. Doolittle made for the bureau a series of studies of the plankton of Lake Keokuk. It was expected that the survey would be repeated after the lake had aged two or three years, and that the results of the two surveys in comparative form would be prepared for publication. Doctor Doolittle

was unavoidably prevented from continuing the investigation, and the data that he obtained in 1914 have remained unpublished. It is desirable to include here an abstract of his observations as prepared by him (next three following sections). The later study of the plankton of the upper Mississippi in 1921 by Doctor Galtsoff (1924) included Lake Keokuk, although he could not, in the circumstances, work this region intensively. In comparing the results of the two studies it must be remembered that there is much reason for believing that a new lake is richest in its first years.

ENTOMOSTRACA

1. In the earlier portion of the season (July) the Entomostraca in the main channel of the Mississippi River and in Lake Keokuk increases in numbers with approach to the dam at Keokuk, as illustrated by the following figures showing the approximate number of Entomostraca per cubic yard of water: At Oquawka, 55 miles from the dam and above its influence, 50; at Burlington, 52 miles from the dam, 100; at Nauvoo, 12 miles from the dam, 150 (over submerged land, 250, and in the protection of weeds, 450); at Keokuk, 2 miles from the dam, 1,500. The increase is attributed to the more favorable conditions accompanying the slackening current, such as the partial loss of sediment in suspension and the greater time allowed both for development of food materials and the multiplication of the Entomostraca. In weeds these favorable conditions are increased and, in addition, there is furnished shelter and fundamental food.

2. The tributaries of Lake Keokuk and the Mississippi River in July show an Entomostracan population greatly exceeding that of the main river and lake at this time. The numbers apparently vary with conditions and somewhat as follows: (*a*) The larger tributaries or arms, without current and with relatively small openings upon the river or lake, may have 50,000 Entomostraca per cubic yard; (*b*) tributaries or arms without current, whose openings upon the river or lake are relatively larger, yield about 2,500 per cubic yard; (*c*) tributaries through which there is current, though scarcely appreciable, possessed Entomostraca at the upper limit of backwater in the number of about 5,000, increasing downstream to about 20,000 until coming within the direct influence of water from the main channel.

3. The river and lake in August showed the following changes in Entomostracan content, generally in the direction of substantial increase in population, as may be seen by comparing the following approximate figures for August with those previously given for July: Above the prism of the dam (Oquawka), in the low water then prevailing, 35; within the prism of the dam at Burlington, 100; at Nauvoo, 1,500 in the main channel (20,000 to 30,000 over submerged land and 150,000 among weeds); at Keokuk, 25,000. The increases are attributed to the same factors that operated in July.

4. In August the tributaries showed differences, but not the same kind of differences as in July: (*a*) In tributaries without current and shut off from the lake by relatively narrow openings or having little means of preventing stagnation the Entomostraca had decreased to 25,000 per cubic yard; (*b*) in tributaries or arms of the lake not subject to stagnation the Entomostracan population had held its own or increased to 50,000 and 100,000 per cubic yard; (*c*) in the river and the tributaries with current the Entomostraca maintained or increased their abundance, the numbers running from 5,000 to 30,000 per yard but being always less in the upper limit of backwater.

5. The Entomostracan population of the lake itself passed its maximum by late August or very early September, though still showing about 5,000 per cubic yard at the latter time.

6. The river and the lake are enriched by the run-off from tributaries, and the river itself below the dam is enriched by the run-off from the lake. The enrichment from the tributaries holds both as to numbers and species, but the species distinctive of a tributary do not survive long in the main channel. Such local enrichment may be 100 per cent. The run-off from Lake Keokuk enriches the river below, so that, at a point 5 miles below, the plankton Entomostraca were found to be from thirty to fifty times as abundant as in the river above the influence of the dam. This was in early August, the season of maximum production of Entomostraca in the lake.

OTHER PLANKTON ANIMALS

Zooplankton other than Entomostraca came under observation as the collections were studied. Chief among these plankton elements were rotifers, which belonged mostly to two genera, Asplanchna and Anuræa. The latter genus was represented by several species and varieties, chiefly *A. aculeata.* There were occasionally present *A. cochlearis*, *A. tecta*, *Polyarthra platyptera*, *Conochilus volvox*, *Triarthra longiseta*, and *Pedalion miron.* Rotifers were seldom absent from the plankton. Until the latter part of the summer they were practically a negligible quantity in the main body of water. In the tributaries they were frequently abundant, and in places they constituted the whole of the plankton. In July and in most of August Asplanchna might be regarded as the more important on account of its size and because it was at times the dominant factor of the plankton; later in the season it became rare. *Anuræa aculeata* was more consistently present than Asplanchna and, while usually occurring in greater numbers, its smaller size prevented its contributing much to the bulk of the plankton. As the season progressed other species of Anuræa were encountered, *A. cochlearis* and *A. tecta* more than others, the latter occasionally being the dominant rotifer. Still other species or varieties of Anuræa and other genera, some of them mentioned above, were found in the plankton after the dominance of Asplanchna had passed. In the latter part of the season—that is, in late August and early September—the lower part of the lake reached a stage of maturity as to succession of plankton forms such as was attained much earlier in the tributaries; then Asplanchna was found and *Anuræa aculeata* became abundant.

Few Protozoa were recognized, yet a species of Euglena formed a very dense bloom upon Skunk River, Flint Creek, and Prairie Slough. Associated sometimes with this Euglena were two species of Ceratium.

Insect larvæ were not found in abundance in the plankton of the lake or of its communicating waters. *Corethra* sp. did enter into the catches once in Lake Keokuk, sparsely in Skunk River, Spring Slough, Green Bay, and more abundantly in Sullivans Slough and Devil Creek.

PHYTOPLANKTON

Algæ rarely occurred in the plankton in measurable quantities until August. Traces of green algæ were, possibly, present from the beginning. Blue-green algæ though more easily detected, were not seen until July 28. The algæ, once having made their appearance, increased as to frequency and amount till near the end of the season of observation in early September. The following general considerations as to the occurrence of algæ stand out clearly from the detailed record.

Green algæ.—(*a*) The volume of green algæ increased with the season. This was especially to be noted in the main body of water and with the approach to the dam at Keokuk. (*b*) In chutes with running water and over submerged land there was an increase of green algæ. (*c*) In the tributaries without current and filled only with back water from the lake the amount of green algæ decreased with distance from the lake. (*d*) In tributaries with running water there were no green algæ except within the immediate influence of the lake. The species of green algæ in the main channel were *Converva* sp., or convervoid forms, with very slight admixture of Pediastrum and Polyedrium. With the passing of the river water over submerged lands and into dead-water tributaries or arms species of green algæ characteristic of stagnant conditions were found. Thus, *Pediastrum boryanum* and Eudorina would appear with considerable regularity, and at times Scenedesmus, Volvox, Glosterium, and Staurastrum.

Blue-green algæ.—Blue-green algæ made their first appearance in late July but were consistently present thereafter in the main channel and in chutes with running water derived from the river or lake. In "dead-water" arms of the lake, blue-green algæ were not encountered. They were likewise absent from tributaries with running water. Apparently food conditions are so changed by chemical action or by the metabolism of green or blue-green algæ that, when not kept constant by renewal of river water, blue-green algæ can not exist. The species of blue-green algæ were few. *Anabaena circinalis* and *A. flos-aquæ* were present and prevailed as the dominant blue-green algæ until mid-August; while encountered once thereafter, they had virtually disappeared by August 20. Clathrocystis was likewise present from the beginning in small amounts, equaled Anabæna by mid-August, and thereafter, with one or two exceptions, was the sole blue-green alga recognized. Nostoc was found over submerged land in the region above Montrose from August 10 to 21. Considerable amounts of Lyngbia were found in water with weedy and stagnant conditions, but these localities were very limited in area. An increase in this and similar forms may be expected in the regions where water Persicaria becomes thickly established.

FISH FOOD

As has been seen, the old rock bed of the river is now covered with silt, but the present lake extends over what was formerly land, and here there must have been, and must still be, much decomposition of land vegetation with consequent depletion of the oxygen supply. On the other hand, one of the chief effects of winds and waves and of the growth of aquatic plants is the reoxygenation of the water. It is quite certain, too, that much of the submerged organic matter has been utilized as food by fishes and by other organisms, notably May-fly nymphs, which in turn serve as food for fish.

The most conspicuous form of acquatic vegetation that appeared in the early years was duckweed (including several species), which was sometimes thick enough in 1915 and 1916 to give a green appearance to large areas of the surface of the lake. Of the larger sorts of exclusively aquatic vegetation the only other kind noticed was the hornweed (Ceratophyllum), which the fishermen found on their lines, and of which thick masses attached themselves to structures immediately above the lock. The simpler single-celled plants, both floating and attached, were noted, but casual observation did not show these to be present in any remarkable abundance. It is worth noting that the only large aquatic plants occurring abundantly away from the shores were forms that do not strike roots into the soil and therefore do not bring into

the biological economy of the lake the fertilizing elements of the bottom soil. (Pond, 1905.) The virtual absence of rooted aquatic plants in the lake proper (noted also by Doolittle) was doubtless characteristic of the immature phase of the lake. As the bottom becomes stabler it is probable that rooted forms will appear. The hornweed is considered a good oxygen producer, but the duckweed is not (Titcomb, 1909, pp. 11, 16; Barney and Anson, 1921); and oxygen may be a matter of importance on the lake, for there were times in 1916 when portions of the open lake near Montrose appeared stagnant.

The author made observations of plants in the vicinity of Dallas City, Ill., and Fort Madison, Iowa, in September, 1917. In the lake principally great masses of duckweed were observed, Spriodela predominating about Fort Madison, and Lemna occurring in great rafts about Dallas City and in Peales Lake, so called. The masses of Lemna seemed to originate over submerged woodlands, whence they floated out into the open lake. No other true aquatic plant (excluding algæ) than Lemna was observed in Peales Lake, but in Green Bay, on the Iowa side (fig. 16), there were in different places acres of smartweed, *Polygonum emersum*, cat-tails, *Typha latifolia*, price cut-grass, *Homalocenchrus* (*oryzoides*?), and tall tick-seed sunflower, *Bidens trichosperma*, all characteristic of swampy rather than lake conditions. Of plants not growing high above the water, there were observed only floating duckweed, Lemna and Spirodela; some pondweed, *Potamogeton* (*natans*?); and the lotus, *Nelumbo lutea*. Within two years after this visit the Green Bay region and adjacent territory of shallow water from a point about 5 miles above Fort Madison to the Skunk River had been inclosed with levees and drained.

The Potamogetons are generally very desirable plants in lakes, but it was observed in Green Bay that the duckweed accumulated in close drift among the floating leaves of the pondweed, making large floating islands, forming a dense shade, preventing the growth of submerged leaves, and, no doubt, when the masses are too large, checking the growth of algæ and other aquatics in the waters beneath. The submerged leaves of the pondweed in such cases were either very small or rotted off. The excessively abundant duckweed in the middle portion of Lake Keokuk at that time was undoubtedly a pest from the point of view of the welfare of fish.

The various species of emergent vegetation mentioned above seemed to serve useful, purposes, both in that their submerged stems gave attachment for algæ (not present to excess) and protection for small aquatic animals, and in that their emergent stems and leaves attracted quantities of grasshoppers and crickets, many of which must have found their way into the stomachs of fish while flying from plant to plant. The floating leaves of the lotus served as temporary lodging places for such insects, while the stems were bored by the larvæ of a moth, probably *Bellura gortynides*.

May flies were enormously abundant on the lake in 1916. (Needham, 1920.) Scattered observations made during the present investigation showed that these are of great importance as fish food, and Forbes (1888, p. 488) found that nearly a fifth of all the food consumed by all adult fishes examined by him consisted of "neuropterous" insect larvæ, the greater part of them being May flies. Their abundance in the lake may be related to a great quantity of decaying land vegetation, for at least some species of May flies eat such food. (Needham, 1905, p. 40; Needham, 1908, p. 262.) Possibly this particular kind of insect will be less abundant when the old terrestrial vegetation becomes exhausted and there develops a more normal aquatic environment with living water plants.

Among the small floating animals and plants (the plankton) the minute Crustacea of many species, grouped together as Entomostraca, are known to constitute an important item and are, perhaps, the principal item in the diet of very young striped bass, sunfishes, black basses, crappies, gizzard shad, minnows, suckers, buffalo fishes, and catfishes; among full-grown fishes they are especially important to the paddlefish, crappies, minnows, quillbacks, and buffalo fishes. (Forbes, 1888, pp. 487, 496.) As the minnows and gizzard shad constitute, in their turn, the chief food of game fishes and others, it is apparent that these tiny animals are very important to the fishery. Doolittle found, in July, 1914, that the entomostracan plankton in the river and lake proper increased in numbers with approach to the dam in notable degree, the number of these small food elements rising from about 50 per cubic yard at the upper end of the lake to 150 at Nauvoo and 1,500 at the extreme lower end of the lake. Later in the season he observed a similar and even more striking contrast between the food supplies under river and lake conditions, respectively, the number of Entomostraca per cubic yard rising from 35 at Oquawka (in the river above the lake) and 100 at Burlington (in the extreme upper end of the lake) to 1,500 at Nauvoo and 25,000 at Keokuk. The increase was attributed to more favorable conditions accompanying the slackening of the current, such as the partial loss of sediment in suspension and the greater time allowed for multiplication of the Entomostraca. A similar difference between the amount of life in rivers and quiet waters occurs in and near the Illinois River. (Kofoid, 1903.) The investigation of this river was very thorough and extended over several years; wide variations were found in different localities and in different months, but the general result showed the quiet waters to be about three and one-half times as rich as the channel; and Kofoid concluded (p. 545) that the small organisms of the river have their source, to a large degree, in impounded backwaters and are maintained to a considerable extent by the run-off of the latter. The bearing of this on the situation in Keokuk Lake is obvious and is indicated further by Doolittle's observations in the waters tributary to this lake (p. 119).

The observations and conclusions of Galtsoff (1924) are most pertinent:

> When the water becomes stagnant, or at least flows slowly, the plankton crustaceans grow more numerous. This has been observed in both Lake Pepin and Lake Keokuk. The increase of Copepoda and Cladocera is especially noticeable in the backwaters of Lake Keokuk, where the crustacean population progressively increases from the upper part of the lake to the dam (p. 414).
>
> The productive capacity of such river-lakes as Lake Keokuk is lessened by the instability of the hydrographic conditions. Nevertheless, the increase of plankton in Lake Keokuk during low stages of water indicates the increase of its general productive capacity (p. 419).

Until the point has been determined for Keokuk Lake by a sufficiently extended investigation, it is perhaps worth while to consider some of the reasons for expecting the lake to have a richer food content that the ordinary channel of the Mississippi. In the first place, it should be kept in mind that the mere motion of the water, by itself, is almost certainly of no importance to small floating animals. Terrestrial man thinks of moving water with reference to fixed bottom or shore. However, the movement of the medium in which they live is of great importance to aquatic creatures as the movement of the earth in space is to man, not because of the motion itself but because it changes the relation to other things. In other words, the motion of the water is significant to plankton organisms only because it is relative—it tends to change the position of the animal with reference to bottom, shores, atmosphere, sunlight, sources of supply, injurious objects, the sea, etc. A suggestive paper on this point has been published by Lyon (1904).

It is well to recall that most fresh-water organisms can utilize the water only after it has fallen as rain and before it is washed into the sea or evaporated. To illustrate the point about to be made, we may take an extreme and hypothetical case. It is obvious that a coastal creek from which the water ran into the ocean within a couple of days of its fall could not have much fresh-water floating life because there would be no time for it to develop. Any retardation of this process of carrying rain to the ocean increases the chance for these animals to reproduce their kind. Accordingly, any checking of river currents should be desirable from this standpoint, although, if carried too far, new and unfavorable factors might appear. It is probable that this checking of progress to the ocean is the chief reason why lakes are richer than rivers. The river is fed constantly, both directly and indirectly, by newly fallen water. The waters of lakes have had a longer history from the time when they were in the form of falling raindrops.

Another reason for expecting lakes to possess more organic life is that they usually have substantial amounts of rooted vegetation, whereas rivers have but little of this (Kofoid, 1903, pp. 236–252); and it is rooted plants rather than drifting plants that enrich the water from the soil (Pond, 1905, pp. 522–525). Evaporation may be of some importance because it replaces, to the extent to which it occurs, run-off to the sea, and thus reduces by that amount the sweeping into salt water of river life; evaporation is greater on lakes (Rafter, 1903, pp. 23 and 39ff) probably because the water is exposed longer and because of the freer action of wind on the water.

One other point is worth noting. The water of a river does not move forward in a simple column but is retarded by the sides and bottom and usually by the air. This retardation of the whole perimeter of a cross section of a river causes extreme irregularity in the character of the movement. The result is complicated by many factors, but it may be said that in a general way a river rolls forward like a wheel, or rather like two sets of wheels (Gilbert, 1914, pp. 248–249), and any given particle of water must be now and again swept from the surface to the bed and up again. It is necessary to diverge a little and recall that green plants are the ultimate food of all creatures, and that they can grow only in sunlight. In the water these plants are represented by (among other things) minute algæ, which constitute an important and perhaps the principal ultimate food of aquatic life. As they can grow only in sunlight, it is probably exceedingly difficult for them to carry on life processes while they are whirled frequently from sunlit areas to the deeper and almost sunless regions of the Mississippi River. Whether or not the interruptions as such are harmful, the reduction of sunlight certainly is.

As the result both of observation and of inference, it has been the conclusion of some investigators that the plankton of a river is produced largely in the tributary waters and is carried into the river, a conclusion that links well with the observation that currents are unfavorable to the production of plankton.[10] Allen, for example, after extensive studies of the plankton of the San Joaquin River in California, says that "water currents above a very moderate speed are distinctly inimical to plankton development." [11] (Allen, 1920, p. 124.) Galtsoff (1924, pp. 412 and 413) gives some observations to show that there is pronounced plankton development in places in the Mississippi River, independent of the contribution of tributaries. It is evi-

[10] For a discussion of this question, see Galtsoff, 1924, pp. 411–415.

[11] A similar conclusion was stated by Schröder in 1899, after studies of phytoplankton on the Oder River, Germany, as mentioned by Galtsoff (1924, p. 413) and adopted by Steuer as Schröder's law.

dent that the question of the direct productivity of the moving waters of large streams merits further investigation.

After many years of investigation of the Illinois River, Richardson (1921, p. 374) concludes that: "Speaking generally, the richest sections of the river floor are those with the least average slope and the slowest current, and therefore with the most abundant sediments." Again he says (p. 376): "In our opinion, and that of the most intelligent and observant fishermen, the lakes are the favorite feeding grounds of the larger and more common fishes, and this opinion is supported by the fact that the lakes have a more abundant food supply per acre and that the heaviest fish yields come from sections where the ratio of lake areas to river is greatest." Richardson estimates the productivity of the lakes and backwaters, as compared with the river, at about 2 to 1 (289 pounds of fish per acre in lakes and backwaters, and 141 pounds per acre in rivers, p. 469).

Whatever may be the general superiority of slack waters over flowing waters in respect of biological productivity, it seems, from the studies of Galtsoff, that Lake Keokuk, although possessing something of the character and the advantages of a lake, is nevertheless not now to be given high rank as a lake. A similar inference may be made from the study of the commercial fisheries treated in the companion report. (Coker, 1930). Lake Keokuk, of course, is still immature as a biological plantation, and its final state can not be foretold, but in any case it is not in high degree free from many of the vicissitudes of river areas.

It has been assumed that an increase of organisms constituting fish food would mean an increase of fish, but even this conclusion has been questioned by the authority who has devoted the most study to the ecology of the fishes of the interior waters of the United States. Forbes and Richardson (1914, p. 494), referring to an increase of organic life in the Illinois River, state:

> The fisheries of the stream should feel the effects of this greater abundance of this important element of fish food; provided, it must be added, that the plankton supply is really at any time a limiting element in the production of fishes, such that we may amend the aphorism, given on another page, to the form: "The more plankton, the more fish." It will, however, be a long time, in the writers' judgment, before the whole economy of fish production in our streams is so thoroughly understood that such a statement will be warranted.

Going even further than this, Juday and Wagner (1909, p. 21) have suggested that an unusually large amount of plankton in a lake might be detrimental to fishes because of the reduction of oxygen resulting from decay. It is evident that more knowledge on the questions involved is needed, but it is probable that rivers, at least, are improved as fish habitats by an increase in their content of food for fish.

SPAWNING GROUNDS

The fresh-water fishes, in general, are believed to spawn in shallow water. Examination of virtually all of the literature on the breeding habits of fishes occurring in the Mississippi River confirms this view for the species that have been observed at spawning time.[12] A great proportion of the newly submerged areas of Keokuk Lake are mostly shallow, and it is a reasonable expectation that these areas will make the lake a nursery for fish, which will help to stock not only the lake but to some extent the section of river above and possibly that below, also. The question may be raised whether or not the lake would have been biologically more pro-

[12] The breeding habits of the river herring of the Mississippi, the paddlefish, and the drum are not known.

ductive had the submerged woodlands been more generally cleared before the lake was filled. One might have the impression that land such as is represented in Figure 16, had it been cleared of vegetation and left to form spaces of open water, would have produced more useful plankton (drifting microorganisms, both plant and animal), would have supported more rooted aquatic plants to serve as food producers and oxygenators, would have contributed less to the deoxygenation of the lake, and would have afforded better breeding places for fish. One might have this impression, but the precise observational and experimental data to substantiate or to contradict such an inference are now lacking. It might be suggested that refuge is a primary need of young fish, and that this is afforded by the submerged brush and fallen trees; but refuge can also be offered by rooted aquatics, which at the same time serve other useful purposes to aquatic animal life. Since the question is continually arising as to the propriety of fully clearing lands that are to be submerged by the formation of lakes and fish ponds, there is obviously a very practical sort of problem in this that awaits critical study.

The preceding paragraphs were written prior to the author's last visit to the lake in 1926, when it was found that the aspect of the lake had changed greatly in respect to the submerged islands and shores. Where forests of dead trees had stood on submerged lands (fig. 16) there were now chiefly stumps and a dense growth of Sagitaria and other aquatic plants (fig. 17). Doubtless some of the trees had rotted at the base and fallen, but it was said that many of them had been cut away during the winter, when residents of the shores could work on the ice and haul the wood away for use as fuel. Where the lake in 1917 had presented the aspect of winding passages amongst heavily wooded areas, there was in 1926 uninterrupted view in all directions. Shallows still prevailed over submerged islands and shore lands, but the water in such places was subject to more severe wave action. (Coker, 1930.) The Green Bay region and adjacent territory, as has been mentioned previously, had been removed from the lake entirely and converted into agricultural lands, thus eliminating some of the best breeding and nursery grounds for fish.

ABUNDANCE OF FISH

During 1914, 1915, and 1916 several visits were made by Stringham to the markets at Burlington, Iowa; during 1915 and 1916 to those at Fort Madison, Iowa, and to fisheries at Nauvoo, Ill.; and during 1916 to newly established fisheries at Montrose, Iowa. There was a tendency at first to complain that fish were less abundant than theretofore; in 1915 this was substantially confined to two species—the Missouri sucker, a southern species never common here, and the shovelnose sturgeon. By 1916 the complaints had about ceased. It seemed clear, however, that the sturgeon fishery was ended for the southern end of the lake, and that it had probably diminished above. Against this, there had been gains in carp, catfishes, and drum, and possibly in buffalo fishes and black bass. As to game fishes, little or no complaint was heard at any time. There was observable a distinct development of the commercial fishery with the use of more and larger apparatus. The statistics of the commercial fishery for 1922, to be discussed later, will show that the gains had been maintained for black bass, catfish, and drum, but not for carp and buffalo fishes. The sturgeon fishery apparently had disappeared in that year.

In 1917 the author interviewed fishermen and dealers at Fort Madison, Dallas City, and Burlington and on Green Bay. The general purport of the information

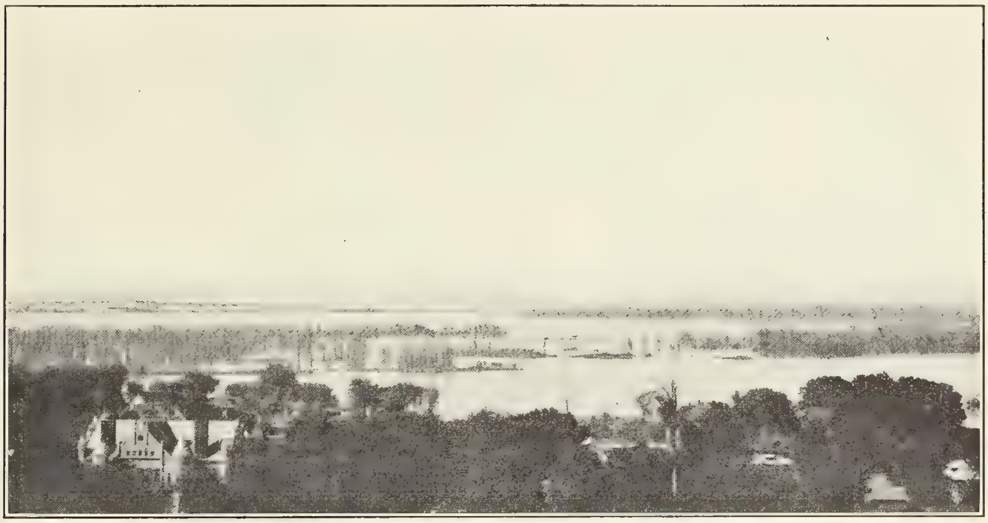

Figure 16.—Overflowed islands opposite Dallas City as they appeared in 1917

Figure 17.—The same region in 1926

received was that "hackleback" (sturgeon), spoonbill cat (paddlefish), and suckers were disappearing, but that carp, buffalo fishes, bass, sunfish, and crappie had greatly increased. There was a marked difference of opinion in regard to catfish, and one dealer stated that catfish, while fewer, were larger. It was also said that whereas there were three commercial fishermen at Dallas City in 1917 there were 35 in 1920. More definite information in regard to the commercial fishery is found in the following section, and the individual species of fish are treated in a later paper. (Coker, 1930.)

SUMMARY OF OBSERVATIONS

Keokuk Lake, formed by the dam at Keokuk, Iowa, extends 42 miles to Burlington, Iowa. The width varies from about ½ to 2½ miles or more, and the total area is about 60 square miles. The greatest depth is about 36 feet. The increase in volume will ultimately be about 14,000,000,000 cubic feet, less the reduction due to filling in by sediment and to reclamation by levees and drainage. The stage, and therefore the area, presumably fluctuates substantially less than that of the river before the construction of the dam. The turbidity and temperature probably are not greatly different from what they were under former conditions, but the velocity of the current has been reduced, the reduction near the dam being very great. The old rock bottom has been covered deeply with silt. The lake, while supporting few rooted aquatic plants, up to 1916 gave evidence of an enriched fish-food content, and there were reasons for expecting that this condition would continue to improve. Land submerged by the widening of the water area should supply favorable spawning beds for game and food fish, but a very large portion of the most favorable areas has been reclaimed for agricultural uses by the construction of levees and by drainage.

DEDUCTIONS FROM THE COMMERCIAL FISHERIES OF LAKE KEOKUK AND LAKE PEPIN

One of the most practical means of determining the effect of the dam upon the fishes of the river would be the comparison of the conditions of the commercial fisheries before and after the construction of the dam. Unfortunately, we have no comparable surveys of the fisheries of the river for such times. This lack has been partly compensated for by surveys of two of the most important regions of fishery above the dam, made soon after the construction of the dam and after periods of 3, 8, and 13 years, respectively. Since the report was first submitted for publication another survey (for 1927) has been completed, and we are enabled to include comments based upon statistical data in manuscript offered by the division of fishery industries. We have not reorganized the section, but we have added a column to each of Tables 6 and 7 and have inserted references to the results of the survey for 1927 wherever pertinent.

It is evident that the dam could not have exerted its full effect upon the fish life of the upper river within a year and that whatever effect may have followed a year after the obstruction was completed should have been more conspicuous in subsequent years. Accordingly, a comparison of the fisheries in Lake Keokuk for 1914, 1917, and 1922 (the dam having been completed in 1913) should give a fair indication of what was happening in that part of the river most immediately affected by the dam. Furthermore, if the dam was far-reaching in its effect by shutting off migratory fishes from the upper river, then a comparison of the fisheries in Lake Pepin, 400 miles (by river) to the north, for the same years should give some indi-

cations of the changes. Under any circumstances, of course, reasonable allowances must be made for such fluctuations as occur from year to year without the intervention of artificial obstructions or improvements, and for such as might result from developments other than the dam.

The full reports of the statistical surveys of the fisheries of the lakes for the years 1914, 1917, 1922, and 1927, respectively, are found in the reports of the Commissioner of Fisheries for the fiscal years 1916 (pp. 58–60), 1918 (pp. 77–80), 1924 (Appendix IV, Fisheries Industries of the United States by Oscar E. Sette), and 1928 (pp. 544–546). The results of the surveys are summarized in Tables 6 and 7.

Attention should be directed first to the fact that between the years 1914 and 1917 prices of fishery products had risen substantially under the influence of war conditions, the average price per pound for all fish being more than 40 per cent higher in the latter year than in the former. The higher price obtainable no doubt proved a stimulus to the fisheries, for the coarser fishes particularly. Again, prices had declined by 1922, and this might be supposed to have an effect. However, since, the returns from all other forms of labor had risen and then fallen in a somewhat corresponding manner, it does not appear at all probable that the stimulation due to price could have had so pronounced an effect as to create an appearance of abundance where actual scarcity prevailed. All comparisons in the text will be made, not on the basis of value but with reference to quantities in pounds of catch.

TABLE 6.—*Fisheries of Lake Keokuk, 1914, 1917, 1922, and 1927*

Items	1914	1917	1922	1927
OPERATING UNITS	*Number*	*Number*	*Number*	*Number*
Fishermen	105	118	122	102
Boats:				
Motor	36	52	58	70
Other	94	80	111	82
Fishing apparatus: [1]				
Seines		1	2	3
Anchored gill nets		12	235	26
Trammel nets	14	17	17	
Fyke nets	1,378	1,368	1,301	1,594
Fish traps		81		815
Dip nets			1	
PRODUCTS	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Black bass	15	4,163	6,200	
Bowfin		26,000		14,055
Buffalo fish	249,900	696,543	113,946	67,872
Carp, German	302,365	762,259	276,431	291,199
Catfish and bullheads	71,535	109,904	183,919	140,343
Crappie	70	17,560	13,770	
Eels	3,800	2,087		
Fresh-water drum or sheepshead	26,860	160,554	65,040	27,538
Pike		20		
Pike perch, sauger			2,280	
Quillback or American carp		5,936		9,880
Spoonbill cat, or paddlefish		927	27,405	1,249
Sturgeon, sand [2]	1,900	454		
Sturgeon, shovelnose			600	
Suckers	4,640	700		
Sunfish	50	13,879	11,590	13,563
Turtles				385
Total	661,135	1,800,986	701,181	566,084

[1] Trot and hand lines are omitted from this statement because data on the quantity in use are not available.
[2] Reported as lake sturgeon in 1914.

TABLE 7.—*Fisheries of Lake Pepin, 1914, 1917, 1922, and 1927*

Items	1914	1917	1922	1927
OPERATING UNITS	*Number*	*Number*	*Number*	*Number*
Fishermen	135	126	219	139
Boats:				
Motor	28	35	109	39
Other	54	55	136	105
Fishing apparatus: [1]				
Seines	14	17	33	23
Anchored gill nets	664	371	351	152
Fyke nets	295	262	95	280
Fish traps	8	14		
Spears			7	4
PRODUCTS	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bowfin	1,534	24,021	16,136	3,334
Buffalo fish	261,250	300,808	340,309	33,449
Carp, German	237,517	467,588	2,578,916	615,242
Catfish and bullheads	26,830	254,249	127,384	53,076
Eels			541	318
Fresh-water drum or sheepshead	131,785	118,304	395,592	113,793
Mooneye, fresh	9,300	7,656		8,976
Mooneye, smoked	1,465	7,250		
Pike	50			
Quillback or American carp	60,605	14,238	47,377	4,835
Spoonbill cat, or paddlefish	8,877	2,923	15,971	1,191
Sturgeon, lake	1,067	512	5,253	
Sturgeon, shovelnose			1,080	
Suckers	18,340	15,260	43,466	31,911
Sunfish	50			
Turtles			442	
Total	758,670	1,212,809	3,572,467	866,125

[1] Trot and hand lines are omitted from this statement because data on the quantity in use are not available.

In the first place, it is observed that the total catch of fish in Lake Pepin in 1917 was 60 per cent greater than in 1914, due in part, no doubt, to increased prices and the war-time demand for fish as a substitute for meats, while the catch in Lake Keokuk had increased 172 per cent; this means that the catch in the lake created by the dam was nearly three times as great in the fifth year of the lake (1917) as in the second year (1914). By 1922 the catch of fish in Lake Pepin was nearly three times as great as in 1917, or nearly five times the yield of 1914; this remarkable change was due in considerable measure, but not wholly, to the increased catch of carp. On the other hand, the catch in Lake Keokuk in 1922 was 61 per cent less than in 1917, although somewhat greater than in 1914. In 1927 the catch in Lake Pepin was comparable to that in 1914, but somewhat larger, while the catch in Lake Keokuk, continuing to decline, was less than in 1914.

The fishes taken in respective quantities of 25,000 pounds, or more, in either lake in any one of the years of report were as follows: Buffalo fish, catfish, fresh-water drum, carp, quillback, suckers, and bowfin. We will consider these severally.

The catch of buffalo fish in Lake Pepin was 15 per cent greater and in Lake Keokuk 179 per cent greater in 1917 than in 1914. The increase in the northern lake is not material, but in the southern lake it appeared in 1917 that the new conditions had afforded opportunity for a substantial development of the buffalo fishes as a natural resource, and this coincided with the statements of fishermen at Dallas City, Ill., a principal fishery point on the lake. The remarkable decline in the yield of buffalo fish reflected by the canvass of 1922 seems at present inexplicable on the ground of any known change in conditions from 1917 to 1922 other than the substantial reduction of area of the lake by reclamation of submerged lowlands. (Coker, 1930.) It may be remarked that buffalo fish was the most valuable fish product of both lakes until 1922, when carp took the lead in Lake Pepin

and catfish in Lake Keokuk. Nevertheless, the take of buffalo fish in the upper lake in 1922 showed a further increase over that of 1917. The surveys for 1914, 1917, and 1922 suggested a steady upward trend in the abundance of buffalo fish in the region of Lake Pepin, but in 1927 buffalo fish were found in extremely small numbers.

The changes apparent in the catches of bowfin (1,466 per cent increase) and catfish (848 per cent increase) in Lake Pepin are not explicable on the basis of any conditions possible of association with the dam. In the case of the bowfin the increase is most probably attributable to the propaganda conducted by the Bureau of Fisheries in 1917 for the greater utilization of this fish in smoked form; thus, from Lake Keokuk 26,000 [13] pounds were marketed in 1917, whereas none had been sold in 1914; and again, none were reported in 1922, but a significant catch appears in 1927. There is no dependable market, apparently, for this much condemned fish, and the fishery goes by vagary.

The large catch of catfish and bullheads from Lake Pepin in 1917 may also have been associated with the "eat more fish" campaign of war times, but it will be noted that even in 1922 the catch was more than four times as great as in 1914 (but only twice as great in 1927). Lake Keokuk shows a steady increase in pounds of catfish taken up to 1922, the yields for the three years of survey being, respectively, 72,000, 110,000, and 184,000 pounds (140,000 in 1927). These figures seem consistent with the expectation that impounded waters of increased area would be favorable to the multiplication and growth of several species of bottom-feeding habit.

A decline in the catch of drum in Lake Pepin had been observed in the seine collections made by the bureau in connection with the propagation of fresh-water mussels, and it had been suspected that this might be attributable to the dam; but the decline of 10 per cent in commercial catch in that lake from 1914 to 1917 was matched by an increase of 498 per cent in Lake Keokuk, which is also above the dam. When we examine the figures for 1922 we find a great increase for Lake Pepin (234 per cent) but a decline of 59 per cent for Lake Keokuk; the catch of drum in Lake Keokuk was still, however, more than twice as great in 1922 as in 1914. In both lakes the figures for yield of drum in 1927 are not notably different from those of 1914.

While the capture of "German" carp, the chief product of fishery (in quantity) in both lakes had virtually doubled in Lake Pepin in 1917, the increase in Lake Keokuk was substantially higher, an increment of 152 per cent being observed. In 1922 the remarkable increase of 452 per cent may be noted for Lake Pepin, while the catch in Lake Keokuk fell 64 per cent, having been even smaller than in 1914. Regarding the latter lake, reference may be made to previous remarks concerning the buffalo fish. The great catch of carp in Lake Pepin in 1922 undoubtedly was due to a notable natural phenomenon, which is discussed in another place. (Coker, 1930). The catch in 1927, while much smaller than in the years about 1922, was still much larger than in 1914 or 1917. In Lake Keokuk the change from 1922 to 1927, as regards the carp, was not significant. The large catch of 1917, for reasons to be mentioned later (Coker, 1930), was due, perhaps, to special conditions.

The quillback or "white carp," on the other hand, shows first a marked decline in Lake Pepin, the catch in 1917 (14,000 pounds) being about one-fourth the catch of 1914 (61,000 pounds), with a partial recovery in 1922 (47,000 pounds) and an ex-

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[13] In the text, figures are given in round numbers in nearly all cases. Exact figures may be found in the tables.

treme decline in 1927. A beginning of a fishery for quillback was seen in Lake Keokuk in 1917, but the quantity yielded was not significant; the fishery did not show in the 1922 canvass but appears again in 1927.

Among the most esteemed of commercial fishes that seem to have declined in abundance in recent years are the paddlefish, or so-called spoonbill cat, and the sturgeons. For both of these there was substantial diminution in the returns from commercial fisheries of Lake Pepin from 1914 to 1917 (67 and 52 per cent, respectively); both seemed to show recovery in 1922 (increase over 1917 of 446 and 926 per cent, respectively), but in 1927 appeared insignificantly or not at all. In Lake Keokuk the paddlefish fishery, not appearing in 1914 and insignificant in 1917 (927 pounds), showed more signs of life in 1922 (27,000 pounds). In 1927, however, the reported yield was only about 1,200 pounds.

The lake-sturgeon fishery is now insignificant, unfortunately, and the figures are too small to be used safely for inference. The sand-sturgeon fishery of Lake Keokuk, of little importance in 1914 (1,900 pounds), dwindled to virtually nothing in 1917 (454 pounds); in 1922 it was represented by a small catch (600 pounds) of shovelnose sturgeon (another name for the same species) but did not appear at all in the report for 1927.

In the case of suckers there was observed a decline of 17 per cent in Lake Pepin from 1914 to 1922 but a great increase in 1922, the figures for the respective years being 18,000, 15,000, and 43,000 pounds (32,000 pounds in 1927). In Lake Keokuk a decline of 85 per cent appeared in 1917, and none were reported for 1922 or 1927.

Eels have never been sufficiently abundant in the extreme upper portion of the Mississippi River to enter substantially into the commercial fishery. They have been more plentiful farther south, as in the region of Keokuk. From 1914 to 1917 there was noted a decline of 45 per cent in the take of eels in Lake Keokuk, and none was reported for 1922 or 1927.

While the statistics of the capture of game fish (black bass, crappie, pike, pike perch, and sunfish) in Lake Keokuk for 1917 and 1922 are suggestive of an increased abundance of such fishes, as would be expected, the figures can not be used safely for purposes of strict comparisons. The laws of both Iowa and Illinois have imposed limitations upon the capture of game fishes and attach conditions to their shipment for sale from certain waters. (Stringham, 1919, pp. 10, 11, and 19.) It is unlikely, therefore, that full and correct information regarding the capture and sale of such fishes is obtainable by statistical agents from the fishermen.

Had we no other canvasses than those of 1914 and 1917, we might draw rather definite conclusions; but the data for 1922 would upset them seriously. Some fish that at first rose quickly in yield failed later fully to maintain the rise; others that seemed distinctly on the decline are found to have come back into prominence. If we should now draw any such conclusions they must be tentative. Certain facts may first be recalled.

1. The canvasses of 1914, 1917, and 1922 reveal a steadily increasing commercial catch in Lake Pepin—in round numbers the successive yields are 759,000, 1,213,000, and 3,572,000 pounds. While the trend showed an interruption in 1927, when 866,000 pounds were taken, it would be difficult to relate this to a delayed effect of the dam.

2. Considering Lake Pepin and the three surveys during a period of 9 years after the construction of the dam: (*a*) Two kinds of fish show increasing yield each

time—buffalo and carp. (*b*) Five kinds show, first, moderate decline, then increase—drumfish, quillback, paddlefish, lake sturgeon, and suckers—and all but the quillback were taken more abundantly in 1922 than in 1914. (*c*) Three kinds of fishes show, first, material increase, then decline—bowfin, catfish, and mooneye—but the catches of bowfin and catfish were still much greater in 1922 than in 1914, while the mooneye was not represented at all in 1922.

3. Lake Keokuk offers a different story: (*a*) Two kinds of fish, at least, show a progressive increase in yield from 1914, through 1917, to 1922—catfish and paddlefish. This is true, also, of the leading gamefish—black bass, crappie, and sunfish—if the figures are to be accepted as correct. (*b*) Three kinds gave greatly increased yields in 1917 but reduced yields in 1922—buffalo, carp, and drum—the yield of drumfish being reduced only as compared with 1917, since it was still as great as in 1914. (*c*) Three kinds show steady decline, the catches being small even in the first year and not appearing in the last year—eels, sand sturgeon, and suckers. (*d*) Two fishes figured only in the products of 1917—bowfin and quillback.

From the statistics of the commercial fisheries we can derive no impression of diminution of fishes in Lake Pepin following the construction of the dam. The quillback and possibly the mooneye offer the only possible exceptions. It must be said, however, that at least two species of buffalo fish play a part in the fishery but are not distinguished by statisticians, and, therefore, there remains the possibility that one has diminished while the other has increased, although there is no evidence to that effect. A similar statement may be made in regard to catfish.

As regards Lake Keokuk, the only kinds of fish of commercial importance in 1914 that were taken in less abundance in 1922 were buffalo fish and carp, fishes that showed increasing yield in Lake Pepin. Eels, sturgeon, and suckers also declined or disappeared; while commercially unimportant in the locality, these fishes are to be regarded as potentially important. However, since lake sturgeon and suckers maintained their place in Lake Pepin, it is evident that they were not excluded from the upper river. The sturgeon of Lake Keokuk (the shovelnose) presents another question.

The statistics for 1927 offer a picture distinct from those of the preceding years of report but do not seem to necessitate substantial modification of the statements made in the two preceding paragraphs. We have to do possibly with one of those occasional years of very poor conditions for the fishery.

The relatively very large catches of buffalo fish, carp, and drum from Lake Keokuk in 1917 offer a nice problem. Possibly we have here another illustration of an apparently common rule of development of newly formed lakes. According to this rule, if it may be so called, there occurs, first, an increase of the smaller animals and plants that constitute the food supply of larger fish; second, a great multiplication and growth of the larger feeders (fish) until the crest of a wave of fish population is attained; third, a depletion of food supply as a result of overabundance of feeders; fourth, depletion in numbers or diminution in average size of fish until the fish population is at the trough of the wave; and finally, an approximate biological balance when fish are less abundant than they were at the crest of the wave and perhaps more abundant than at the trough of the wave. If this explanation applies, later surveys may show improvement. If the reclamation of submerged lands is the cause of the fall of the catches, no material improvement is to be expected. It is

important that further surveys should be made. (No improvement, but the reverse, is shown by the survey of 1927.)

It may be thought that more detailed consideration should be given to the matter of changes from year to year in the amounts of the several kinds of gear in use. Undoubtedly such changes have some effect on the returns, particularly in the cases of fishes of minor importance. As regards the fishes of major importance, shifts in the use of gear are likely to be the result rather than the cause of variable yields of particular fishes. On the whole, after studying that question with some care, we doubt if the changes of gear reported could have had such an effect as to modify significantly the general aspect of the returns. It must be said, however, that for strictly accurate comparisons of the catches of different years it would be necessary to consider not only the numbers of each kind of apparatus used in each year but also the number of days and hours that each piece of apparatus was employed. It must never be forgotten that the "margin of error" in the use of such statistics is very broad at the best; we can only say that we do not believe it is wide enough to make fish appear abundant when they are scarce or rare when they are actually abundant.

NOTES OF A. S. PEARSE ON CHANGES IN FISH FAUNA IN LAKE PEPIN

Before leaving the subject of fisheries in Lake Pepin, reference should be made to two systematic examinations of fishes in that lake conducted, respectively, by Dr. George Wagner, of the University of Wisconsin in 1903 and 1904 (Wagner, 1908), and by Dr. A. S. Pearse, of the same institution, in 1920 (Pearse, 1921). Doctor Pearse makes the following comparison of conditions existing in 1903–4 and 1920, respectively, as regards the more important species of fish:

> Marked changes have evidently occurred in the fish fauna of the lake since Wagner (1908) made his observations in 1903 and 1904. The lamprey eel is no longer common, probably because its usual host, the spoonbill, has decreased in numbers. Wagner says (p. 27) "The spoonbill (paddlefish) is one of the most abundant forms in Lake Pepin throughout the summer." In 1920 this species was rather uncommon. Again Wagner says that the rock sturgeon is "not uncommon" and that the hackleback is rare. In 1920 (Table 2) the hackleback was abundant and the rock sturgeon (not seen by the writer) very rare. Wagner took no bullheads except the tadpole cat. Three species were common in 1920. The buffalo (*Ictiobus cyprinella*) was "very abundant" and is now rather uncommon. It has been replaced by the carp, which in 1920 led all other species in commercial value. Wagner found the skipjack (river herring) "very common," and in 1920 it was quite rare. He found the rock bass very common, and the young "extraordinarily numerous alongshore." In 1920 no rock bass were caught, although special efforts were made. The local fishermen all agreed that it was an exceedingly rare fish. The perch was rare in 1904, and in 1920 was rather common. Small largemouth black bass are no longer so abundant alongshore as to be a "nuisance in fishing with a minnow seine."
>
> The spoonbill, rock sturgeon (lake sturgeon), and buffalo have evidently been more or less "fished out" during the past 15 years, and the last has been replaced by the carp, which has similar habits. Wagner probably took no bullheads because he did not fish with trot-lines. The writer sees no apparent reason for the marked decrease of the skipjack and rock bass.[14]

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[14] Neither of these last-mentioned fishes plays a part in the commercial fishery. The rock bass, however, is important as a game fish and local food fish, and the "skipjack," or river herring, is of great economic importance as a carrier of the larval stage of one of the most valuable commercial mussels.

CONCLUSIONS

It remains to give our special observations regarding the fishes of commercial importance possibly affected by the dam and to consider each in the light of all available information concerning them. For reasons of practical convenience this is made the subject of a special report to follow, entitled "Studies of common fishes of the Mississippi River at Keokuk." (Coker, 1930.) However, it is appropriate here to give our conclusions in full, and this is done with the understanding that the data supporting many of the conclusions presented are to be found in considerable part in the other report.

The dam acts as an effective barrier to upstream movements of fishes, being impassable in that direction for any kind of fish except in so far as they may pass through the lock. The evidence indicates that there is no distinct migratory movement of fish through the lock. The location of the lock with reference to the currents and the manner and extent of its operations preclude its functioning as an effective fishway.

Little evidence was found to indicate that free migration past any one given point in the river as far north as Keokuk is of vital importance to any species of fish of the region except the eel, river herring ("skipjack"), Ohio shad, blue sucker (probably), and possibly the rock sturgeon. Each of these fish is mentioned severally in the following paragraphs.

Fish may pass over the dam in a downstream direction, but we could find no evidence that this occurred to a detrimental degree for any kind of fish, excluding the eel.

Reports that fish in upstream migration were deflected in quantity up the Des Moines River, a tributary entering the Mississippi River just below the dam, were carefully investigated on two occasions in different years and were found to be manifestly without foundation in fact on these occasions.

Injured fish, chiefly paddlefish, frequently are seen floating in the swift current just below the dam and near the western shore. Many experiments were made, but the cause of the injuries could not be determined. It was learned by experiment that carp and goujon could pass over the dam without evident injury, and that it was possible for paddlefish to pass downward through the turbine chambers without observable injury. It does not follow, of course, that fish could not receive injury in making such passages. There is the possibility that the injuries resulted from encounters with submerged piling in the extremely swift waters of the tailrace.

Studies of the records of river level for both Davenport (above the lake) and Keokuk (below the lake) for the years 1910 to 1919, inclusive, show that the fluctuations tended to become more marked in the later years at both places.

While a lake of considerable expanse and depth now covers the site of the former Des Moines Rapids and adjacent sections of the river and its bordering lowlands, typical lakelike conditions have not developed and probably never will develop to an extent comparable to the conditions in Lake Pepin. Both lakes represent impounded portions of the river—the one artificially impounded, the other naturally impounded. The differences between the two are attributable to the greater volume of the inflowing river relative to the area of Lake Keokuk, the greater amount of sediment carried by the river in its lower course, and the reclamation of a very valuable portion of the lower lake for agricultural uses. The increase of plankton in Lake Keokuk

suggests the increase of its general productiveness, but the plankton development in that lake has not been found comparable to the development in Lake Pepin. Lake Keokuk is subject to more of the vicissitudes of ordinary sections of the river.

The statistical surveys of fisheries in Lake Pepin for 1922, when compared with surveys of 1914 and 1917, indicate an increasing catch of paddlefish, but oral reports in 1926 and the survey of 1927 indicate a recent scarcity of this and other commercial fishes. The surveys made for Lake Keokuk show increasing yields in 1922, with a corresponding drop in 1927, and this is in accord with the reports of commercial fishermen. The evidence indicates that the species finds in Lake Keokuk favorable conditions for reproduction and growth. The effect of the power development, if any, on the paddlefish fishery of the upper river is favorable. However, somewhere in connection with the dam a noticeable number of paddlefish receive serious injuries, the cause of which we have been unable to ascertain.

The decline of the rock sturgeon in the upper river can not be associated with the the presence of the dam, as that fish had been virtually lost to the upper part of the river before the dam was built. The shovelnose sturgeon, small but very valuable, may be declining in importance in the river above the dam, but the evidence is not very clear. Further inquiries should be made during a season of good flow of water, such as had not prevailed for several years before 1926. The lake offers no advantages for it. Since the fish seems to be holding its own better below the dam, it is possible that breeding conditions are better there and that the fish would be more abundant in the upper river were the dam not an obstruction to its upward range. Some breeding evidently occurs above the dam.

Gar pikes are undiminished in numbers, if not increasing, but that condition can not well be associated with the dam. The yellow sandshell, the most valuable of all mussels, which propagate with the aid of gar pikes, is greatly increasing in abundance in the upper river, a condition very desirable in itself but probably due to the increasing numbers of wing dams built in aid of navigation and serving as protection to areas of relatively still and shallow waters along the shores, where the sandshells may thrive.

The bowfin (or dogfish), formerly despised generally, is now in some demand, but is not found in the upper Mississippi in such abundance as would be expected. Its extremely predacious habit makes it an undesirable element.

The mooneyes appear to have been unaffected by the dam. The gizzard shad, very valuable as food for other fishes, might be expected to multiply abundantly in the lake, but we have no evidence yet of its notable increase.

The river herring, while still abundant below the dam, does not now appear in the upper river in anything like the numbers observable in former times. Undoubtedly it breeds above the dam as well as below, but we are led to the conclusion that the upper river formerly was stocked largely by migration from more southern waters, and that the effect of some comparatively recent change has been to cause a great reduction in the abundance of river herring in the upper river. That the dam was the effective factor in this change is strongly evidenced by the fact that diminution in numbers of river herring was observable immediately after the dam was built and was most pronounced at that time. Apparently there has been a partial recovery, but river herring are found now in far less abundance than formerly. The valuable niggerhead mussel, dependent in nature upon the river herring for its early development, is gradually declining in importance in the upper Mississippi. We can not, of course, say to what extent the decline is due to the intensive fishery for a mussel of

very slow growth or to what extent it is attributable to the reduction in numbers of the fish upon which the mussel is dependent.

The Ohio shad in upstream migration at the season of spawning is stopped by the dam. Unfortunately this fish has been so little known that we have no information whatever regarding its occurrence in the river before the dam was built.

Eels bred in the sea are virtually estopped from passing into the upper river. Small eels are reported to occur at times in substantial numbers at the base of the dam. The eel may be expected to become quite rare in the Mississippi and tributaries entering it above Keokuk unless young eels can be planted above the dam.

Of the catfishes, only the Fulton cat is affected adversely by the dam. It is there stopped in northward migration, but it probably never ascended the river far above the site of the dam. It seems certain that they were once seasonally abundant in the Des Moines Rapids, which are now submerged by the water of the lake.

There has occurred a notable increase in the local abundance of the channel catfish and niggerlip catfish in Lake Keokuk, due undoubtedly to the favorable conditions provided by the lake for breeding and growth of catfishes.

Excluding the blue sucker, none of the "suckers" seems to have been unfavorably affected by the dam except in so far as the lake, with its still waters, has made that particular locality unfavorable for such species as are addicted to swiftly flowing water.

The blue sucker presents a problem. Up to about the time the dam was built the blue sucker was very abundant in swift water for a limited season in each year. Since that time it has almost disappeared from the river above the dam and, seemingly, below it as well. As the indications are that the fish was strongly migratory in habit, there is the probability that the dam has shut it off from its best breeding grounds and that the sucker stock of the river above and below the dam has suffered in consequence. We do not know of a type of fishway that could have been used to obviate the difficulty.

There is found no reason to believe that the dam, acting as an obstruction, has had any significant effect upon the abundance of the buffalo fishes in any parts of the river unless, perhaps, quite locally. It has been said by one experienced fishery manager that "southern" buffalo were greatly diminished in Lake Pepin after the dam; but to suppose that Lake Pepin is contingent upon the river 500 miles below for its stock of any species of buffalo fish involves assumptions regarding the natural history of buffalo fishes that are not justified by any body of evidence.

The favorableness of conditions for reproduction of buffalo fishes and carp in Lake Keokuk unfortunately has been reduced by the drainage of large areas of overflow lands since the dam was built.

The dam as a barrier has had no significant effect upon the basses, crappies, and sunfishes. The lake offered favorable conditions for the multiplication and growth of such fishes, but its advantages have been lessened by the drainage of the Green Bay district.

As regards the pike perches, it is not probable that the dam has any significant effect upon the abundance of the fishes unless it be comparatively local. Too little is yet known in reference to the migratory habits of the sauger, the only species that could be affected seriously by the dam.

There is no evidence of effects, one way or the other, upon the white bass or the yellow bass.

The indications are that the dam has had no marked effect upon the general abundance of drumfish in the river either above or below Keokuk, although it may interfere with local nomadic movements.

Fishes that seem not to be affected significantly by the power plant (except locally) include nearly all the commercial and game fishes. Fishes that it seems likely have suffered real detriment are the river herring (and with it the niggerhead mussel), the Ohio shad, the eel, and the blue sucker. It is possible that the shovelnose sturgeon also has been affected unfavorably. The Fulton catfish has been shut off from the upper 50 or 100 miles of its former range. Fishes that have derived benefit from the development of the lake are the paddlefish, catfishes, buffalo fishes, carp, black bass, crappie, and bluegill (?). The benefit to the paddlefish may extend far up the river; the benefits in the other causes are probably localized, and they were far more notable before the Green Bay district was drained.

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STUDIES OF COMMON FISHES OF THE MISSISSIPPI RIVER AT KEOKUK[1]

By ROBERT E. COKER, Ph. D.
Professor of Zoology, University of North Carolina

CONTENTS

INTRODUCTION

In the course of an investigation begun in 1913 relative to the fish and fisheries of the upper Mississippi River as possibly affected by the great dam for hydroelectric power built across the river between Keokuk, Iowa, and Hamilton, Ill., much information was gathered, by observation and otherwise, regarding the chief fishes of the

[1] Submitted for publication Sept. 28, 1928. Prepared at the same time and based upon observations and collections made during the same period in which this report was prepared is an accompanying paper entitled "Keokuk Dam and the fisheries of the upper Mississippi River" (Bulletin, U. S. Bureau of Fisheries, Vol. XLV, 1929, pp. 87–139), in which are presented the details of studies and experiments concerning the possible effect upon the commercial or sports fisheries of the power dam at Keokuk, Iowa. Inasmuch as the present paper necessarily includes frequent reference to such effects, the two papers should be consulted together by those interested.

region.[2] About 60 species of fish were found in the Mississippi within 10 miles below the dam, while about 10 others were collected in near-by waters. About 30 species are common enough to be of direct or indirect economic importance; the discussion that follows is restricted principally to species of which 50 or more examples were observed. Each species is considered, as far as practicable, with reference to its economic importance, its breeding habit and range, its known or supposed migrations, its seasonal occurrence, and its abundance at Keokuk and in Lake Pepin (400 miles above) both before and after the construction of the dam. We have not hesitated to cull data from all available sources regarding the natural history of the significant species, not only because such information formed the necessary background for our own study but also in order that the reader might be able to make his own inferences regarding the probabilities or possibilities of the effects upon the several species both of the dam as an obstruction and of the pool above the dam as a body of water presenting a new set of conditions for feeding, growth, and breeding.

One thing in the account that we think of value is the directing of attention to the surprising gaps in our knowledge of the most elemental facts of the life histories of common fishes. To say nothing of the paddlefish and hackleback sturgeon, who knows when, where, and under what conditions occurs the breeding of fresh-water drum, blue sucker, river herring, or Ohio shad? The last-mentioned fish, potentially an excellent food fish and fairly abundant, as our observations indicate, has not even been recorded hitherto from the Mississippi River. Who has observed the breeding (in nature) of any of the larger catfishes of the Mississippi Basin? Where is the "niggerlip" catfish during the 10 months of the year, when it is rarely taken by commercial fishermen? Who has studied the modifications of form and color corresponding to habits or ages of any of the catfishes or buffalo fishes? There are excellent opportunities for useful studies of fishes that can be readily found in various streams of the Mississippi Basin.

Paddlefish or spoonbill cat. *Polyodon spathula* (Walbaum)

The paddlefish is valued for its flesh, used both fresh and smoked, and especially for its roe, which is made into caviar. It is of peculiar general interest as a species that is almost unique, being markedly different in form and structure from any other fish now living except a single species occurring in certain rivers of China. Sharklike in form, but not in behavior or in quality of meat, it ranks as one of the most estimable aquatic resources. At times it has seemed upon the verge of extermination from overfishing or other unfavorable conditions, yet apparently it shows remarkable powers of endurance or recuperation. Since the roe of an individual fish may weigh 10 to 15 pounds and is sometimes worth more than $2 a pound, a large paddlefish may represent a very valuable catch. Until recently, at least, the flesh of the fish was not generally sold under its own name but might appear in the markets fresh or smoked under the name of "sturgeon." In Lake Pepin, in fact, a common name used by the fishermen and applied to the living fish some time ago was "shovelnose sturgeon."

The paddlefish is found only in rivers and lakes of the Mississippi Basin and in some other tributaries of the Gulf of Mexico. While it is rare in shallow tributaries

[2] As related in connection with the companion report (Coker, 1929), the studies upon which the two papers are based were made during many years. For some time Emerson Stringham, then scientific assistant in the Bureau of Fisheries, collaborated in these studies. He spent the greater part of two years at Keokuk making experiments and observations that have contributed materially to both reports. The acknowledgments made in the other report apply as well to the present paper.

Figure 1.—Paddlefish about 4 feet long, photographed by Dr. A. D. Howard

and has been supposed to prefer waters exceeding 10 feet in depth, yet it occurs throughout nearly the whole course of the Mississippi River and is widely distributed in the basin; thus, one of the largest specimens of record was taken in Lake Chautauqua, N. Y. The more important fisheries for paddlefish have been in lakes of Louisiana, Mississippi, and Arkansas and in the Ohio, Illinois, and Mississippi Rivers (in the latter as far north as Lake Pepin, between Minnesota and Wisconsin). Paddlefish usually are taken along with catfishes, buffalofishes, and carp in large seines, which may be hauled from barges by the use of reels or pulled ashore by the use of stationary winches. They are also taken in hoop nets and in floating trammel nets fished at night. In the Mississippi in recent years the sizes generally taken range from 4 to 12 pounds. Large examples, 25 or 35 pounds in weight, are rare, but fish of 12 or 15 pounds weight are said to be more common in the last year or two (preceding 1926) at points on Lake Keokuk.

In spite of the most careful searches by various investigators working in many localities, virtually nothing has yet been learned concerning the breeding habits of the paddlefish. It is reported to breed in Louisiana (Stockard, 1907; Alexander, 1915), and it has been found in a nearly ripe condition at Louisville, Ky. (Evermann, 1902.) There is also some testimony that it spawns in central Illinois. (Forbes & Richardson, 1908; Richardson,1913, p. 405.) Fishermen and dealers at and near Keokuk report that they frequently take examples containing eggs and that the roe is marketed for preparation as caviar. Dr. Paul Bartsch, who lived in Burlington, Iowa, from about 1885 to 1896, has stated orally that in the spring these fish entered the sloughs on the Illinois side of the river in great numbers, and that specimens examined by him contained roe in an advanced stage of development. Wagner (1908, pp. 27–31) examined about 1,500 specimens from Lake Pepin, between Minnesota and Wisconsin, from June 11 to September 1, but none were found that were nearly ripe or recently spawned. He purchased there three young paddlefish, each measuring about 25 centimeters (10 inches) over all, among the smallest specimens ever collected.

Stockard (1907), from observations made in Louisiana and Arkansas, concluded that the breeding season in that part of the country was about the middle or latter part of April. Allen (1911) obtained specimens 4 to 6 inches long on July 1 near Cairo, Ill., and larger ones of 6 to 12 inches in length late in August or early in September. He inferred that the breeding season was in March. Dr. A. D. Howard, from observations made during several seasons (1919–1921) in Louisiana and some in Arkansas, concluded that spawning occurred early in spring. The Fairport station obtained a small specimen 26.1 centimeters in total length (about 10.3 inches) taken on a trot-line fished at a depth of 25 feet in the center of the channel of the White River, Ark., on June 19,1922.

All the evidence indicates that the paddlefish breeds either in late winter or early spring, and as young specimens have been obtained at Cairo, Ill.,and Lake Pepin, Minn., and (during the course of this investigation) near Montrose, Iowa, there is at least some evidence to indicate that its breeding activities are confined neither to the northern nor to the southern extremes of its territory.

There appears to be lack of any definite record of an extended migration of paddlefish in an upstream or downstream direction. It has not been known whether the paddlefish of Louisiana and Minnesota were bred and reared in their respective localities or whether migrations occurred between the extreme limits of the range of the

species. A "spring run" of paddlefish is sometimes spoken of, but this expression is used so generally and loosely that no particular significance can be attached to it as bearing upon a migration of the character in question. Stockard (1907, p. 761) furnishes observations of a conspicuous lateral migration from rivers to lakes and from lakes to rivers. This statement may be quoted:

> During the spring, when the water of the Mississippi River rises for several feet and backs into the bayous, thus establishing connections with the large lakes, Polyodon begins immediately to come into the lakes from the river and continues to come in large numbers so long as a sufficient connection is maintained. To do this it must often make long journeys through rather shallow water, in which many obstructions, such as bushes and trees, are frequently met. Thus, it finally reaches the lakes in a rather emaciated condition and with its body scarred and scratched. * * *. It is equally true that the fish in the river-lakes (those lakes more directly connected with the river) migrate out into the river when the water begins to back in during the spring, so that fishermen often abandon their fishing in these places at such a season, since most of the desirable Polyodon have made their escape.

Wagner (1908, p. 27) says: "Seemingly the spoonbill is of a rather roving disposition, cruising up and down the lakes in large schools." He observed that it might be taken abundantly in the seine one day, while the next day there might be none. At various places along the river commercial fishermen speak of "shoals" of paddlefish, suggesting a gregarious habit.

The peculiar feeding habit of the paddlefish doubtless makes necessary a relatively active life with extensive local migrations in search of food. The paddlefish, unlike other fish of like size, does not take large animals as food but subsists upon the minute plant and animal life, which it obtains by straining enormous quantities of water. It must be in constant movement when feeding, and its daily local distribution must be affected by conditions affecting the abundance of plankton food supply.

Dr. R. A. Muttkowski determined the stomach contents of five paddlefish taken by Stringham at various dates from April to August and found the material to consist chiefly of insect larvæ (burrowing May-fly nymphs, other May-fly nymphs, caddisfly larvæ, and odonate larvæ) and insect remains, with small quantities of plant and other débris, pieces of wood, and some parasitic nematodes. The stomach contents of a paddlefish submitted to the Bureau of Fisheries from Louisiana and examined by the author contained almost exclusively the pelagic and translucent Corethra larvæ. Such observations indicate that the paddlefish may feed either at the bottom or in the water above, a matter about which there has been difference of opinion.

There is one other matter for remark in reference to the paddlefish at Keokuk. The author has not infrequently observed paddlefish taken below the dam having the snout broken squarely off, the wound being fresh. We have not been able to discover the cause of this injury. Experiments elsewhere described (Coker, 1929, p. 111) show that the fish can be passed over the spillways or down through the turbine without experiencing such injury, but unquestionably there is some condition about the dam that permits of the paddlefish incurring the loss of its snout. It is conceivable that such an accident could occur to a paddlefish attempting unwittingly to pass between the submerged piles of old cofferdams and other construction work in the exceedingly swift waters of a tailrace. This fish, as is well known, has very deficient sight (Hussakof, 1911, p. 246), and in finding its way it apparently depends chiefly upon the delicate tactile sense organs in its snout. In cases of this kind the sensory warning might well come too late to save the snout. It has been suggested

that the injuries might occur where spillways were opened and water descended with irresistible force upon fish playing in formerly quiet pools below the dam. It is interesting, in this connection, to note that Stockard observed a well-conditioned paddlefish that had lost the greater portion of its "bill" but that evidently had thrived and grown without it. (Stockard, 1907.) Whatever the cause, the condition continues to the present time, for, according to reliable local reports in 1926, injured fish were still, and not uncommonly, seen floundering ineffectually in the river for at least 20 miles below the dam.

Just after the dam was completed an unusual abundance of paddlefish and other fishes was observed by Surber (July 10 and 11, 1913) in the water just below the dam. (Coker, 1914, p. 10.) The paddlefish was apparently third in abundance among the species noted. During the present investigation examples have been taken in the vicinity of Keokuk in each month of the year except November and December. No observations have been made in December, however, and few in November, so that it is a fair inference that the fish is present at all times of the year.

On the occasion of a visit to Keokuk in August, 1914, the paddlefish was common in the swift waters eastward of the tailrace, where it could be captured in floating trammel nets employed at night. During the whole of 1915 and in 1916 until late summer it was taken only occasionally; this may have been due to high water, but seining was not practiced during these times in localities where the paddlefish were taken subsequently. From August 1, 1916, until observations were stopped a month and a half later from 100 to 600 pounds per week were taken, as learned by weekly inquiries at the market. These were found in quiet waters between wing dams.

In Keokuk Lake (above the dam), near Montrose, Iowa, small paddlefish were taken in a seine during the late summer and fall of 1916. Earl Bauter, one of the owners of this seine, reported on August 9 that they had caught 8 or 10 during two weeks or so before that date; on August 24 he said they had taken 30 or 40 young in one haul and some nearly every day; on September 15 his brother, Fred Bauter, stated that they were getting about a dozen small ones in each haul. During the same period they took adults rarely, and these they sometimes returned in the hope that they would breed. Three young collected by them in August measured 38, 39, and 40 centimeters (15–16 inches) over all (our measurements), the snout making over one-third of the total length. These were possibly hatched in the same season, and their presence gives strong indication that the species breeds in the lake or river north of the dam. Five adults taken near Keokuk in the spring of 1916 were examined, but none was in an advanced stage of sexual development. On August 23 two men who dressed about 100 during the preceding week said that none of them contained eggs; that is to say, eggs such as would be visible on casual examination.

Considering, then, the facts that the paddlefish is found at all seasons at Keokuk and that very young specimens have been taken as far north as Minnesota, as far south as Cairo and Arkansas, and in the lake just above the dam three years after the completion of the dam, we find little ground to suspect that a barrier at Keokuk will necessarily exterminate the species either above or below the dam.

It is desirable to consider the available figures as to the extent of the commercial fishery. From computations based on the report of Smith (1898) this species appears to have constituted 2.4 per cent in quantity of the whole Mississippi River fishery product in 1897 [3] and 1.4 per cent of that part taken in Iowa, it being sixth in

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[3] Roe sold separately for caviar not included.

rank among fishes taken from the Mississippi in Iowa. From computations based on the report of Townsend (1902), it constituted 5.1 per cent of the fish from the Mississippi River and tributaries in 1901 and 1.5 per cent of the fish taken in the whole of Iowa, standing eighth among Iowa fishes. From computations based upon the report of the United States Bureau of the Census (1911) it constituted 2 per cent of fishes from the Mississippi River and tributaries and 0.2 per cent of fishes taken in the whole of Iowa in 1908, rating fifteenth among Iowa fishes; but this report shows that the Iowa paddlefish were all taken in the Missouri River district.

Unfortunately, statistical figures regarding the paddlefish (prior to 1914) can not be regarded as accurate or complete because of the extent to which the fish, especially from northern waters, has been marketed under a false name. Neither Minnesota nor Wisconsin, for example, are credited in the census report for 1908 with the production of paddlefish, although paddlefish undoubtedly were being marketed then from Lake Pepin under the name of "shovelnose sturgeon."

In Table 1 comparison is made between the reported catches of paddlefish in 1899 (Townsend, 1902) and 1908 (U. S. Bureau of the Census, 1911), respectively, by States, arranged in the order of the size of the catch, in pounds, in 1899, and also between the reported catches of 1908 and 1922.

TABLE 1.—*Paddlefish product in 1899, 1908, and 1922, by States*[1]

State	Catch		Increase or decrease, 1908 compared with 1899		Catch, 1922	Increase or decrease, 1922 compared with 1908	
	1899	1908	Decrease	Increase		Decrease	Increase
	Pounds	*Pounds*	*Per cent*	*Per cent*	*Pounds*	*Per cent*	*Per cent*
Mississippi	948,305	463,000	51		352,260	20	
Arkansas	551,405	71,000	87		338,612		79
Tennessee	211,185	195,000	8		54,015	77	
Illinois	195,174	402,000		[2] 106	101,700	75	
Missouri	190,931	128,000	33		36,850	70	
Kentucky	147,260	65,000	56		15,015	77	
Louisiana	132,200	132,000	0	0	422,478		69
Iowa	36,390	6,900	81		48,930		86
Indiana	34,125	0	100		1,500		(3)
Nebraska	16,375	20,000		22	10,800	45	
Kansas	7,850	1,500	81			100	
South Dakota	2,050	0	100			100	
Texas	0	32,000		100	26,310	18	
Ohio	0	1,600		100		100	
Minnesota [4]							
Oklahoma					550		(3)
Wisconsin					29,471		(3)
	2,473,250	1,518,000	39		1,438,491		

[1] Roe sold separately for caviar not included. In 1922 the amounts of caviar were: Mississippi, 1,563 pounds; Arkansas, 4,077; Tennessee, 200; Kentucky, 150; Louisiana, 5,908; Texas, 500.
[2] Great increase in all Illinois River fisheries occurred between 1899 and 1908 due to increased volume of river after construction of Chicago drainage canal.
[3] No report for 1908.
[4] The lack of report for Minnesota for all years is not understood. Possibly the paddlefish were included with other fish, such as shovelnose sturgeon or catfish. Paddlefish have been regularly taken on the Minnesota side of Lake Pepin for many years.

After all reasonable allowance for inaccuracies, the substantial decline of the paddlefish fishery throughout the region of report remains evident. The decline between 1899 and 1908 would have been even more notable but for the great increase in fish from Illinois, due in large measure to the exceptionally active and successful fisheries that were prosecuted on the Illinois River in the years immediately preceding and following 1908. Notable increases in 1922 are found only for Arkansas, Louisiana, and Iowa.

Statistical canvasses of the commercial fishery in Lake Pepin and Lake Keokuk, respectively, were made by the Bureau of Fisheries for 1914, 1917, 1922, and 1927. (Reports previously cited in Coker, 1929.) No catch of paddlefish was reported in Lake Keokuk in 1914, but 927 pounds were reported in 1917, 27,405 pounds in 1922, and 1,249 pounds in 1927. The commercial fishery for paddlefish in the lake in the earlier years was thus practically negligible, becoming of interest only in 1922. In Lake Pepin we find 8,877 pounds taken in 1914, 2,923 pounds in 1917, 15,971 pounds in 1922, and 1,191 pounds in 1927, the percentage of the weight of paddlefish to the entire catch for the lake being 1.17 in 1914, 0.24 in 1917, 0.45 in 1922, and 0.73 in 1927.

The decreased abundance of the paddlefish in Lake Pepin, evidenced by the comparative figures of 1914 and 1917, was confirmed by various observations. Wagner (1908), speaking of his observations in 1903 and 1904, said that the paddlefish was one of the most abundant fish in the lake throughout the summer. Pearse (1921) worked on the lake in 1920 and found the species "rather uncommon." When the author visited Lake Pepin in July, 1913, a catch of several hundred pounds of paddlefish in the big seine was not considered an event; while on the occasion of a visit in September, 1921, it was learned that the first paddlefish of the season, four in number, had been taken the preceding day (September 2). A catch of 20 examples on the 3d was greeted by the fisherman as a big find. While there has, no doubt, been a reduction in numbers of paddlefish throughout their range within the last 30 years, the decline of the fish in Lake Pepin seemed particularly rapid during the years immediately following the construction of the dam, although in the catch of 1922 there was a suggestion of recovery in that lake, as in Lake Keokuk. In each lake, however, an extreme slump was evidenced by the statistical canvass for 1927.

In 1926 there were no encouraging reports regarding paddlefish in the general vicinity of Lake Pepin, but the last few years have been bad for all fish. At Lynxville it was said that paddlefish were being taken abundantly in the Wisconsin River. About Fairport, Iowa, paddlefish are still taken, but not in substantial numbers; some fishermen regard the water conditions as unfavorable. Reports concerning the abundance of spoonbill below the dam (Keokuk to Canton) were not consistent. On the other hand, at all points on Lake Keokuk the fishermen were virtually unanimous in the opinion that paddlefish were becoming decidedly more numerous in the lake. It is always surprising to hear a commercial fisherman say that any desirable fish is increasing in abundance, but in this instance the reports conformed in detail. Not only were there more paddlefish, but each year the average size was greater, and several had made the usually rare observations of paddlefish 8 to 12 inches in length. These reports, taken together with the statistical data and the collection of small spoonbills at Montrose in 1916, left no doubt that paddlefish were breeding in Lake Keokuk and that the fish had received a new impetus to multiplication and growth in that part of the river. However, only a small catch was reported for 1927.

As regards the effect of the propagation of paddlefish in Lake Keokuk upon the upper portion of the river, no definite forecast can be made. The water of the river below the twin cities and as far down as Lynxville is reported to be increasingly dirty from pollution and lack of volume, and appearances give some support to the reports. In the vicinity of Fairport, below the tricities of Davenport, Rock Island, and Moline, not only was the appearance of the water bad in August, 1926, but we saw some dead fish and quantities of dead yellow sandshells, some empty and some with the meats

still in them. In such circumstances we would not venture a prediction that paddlefish, however abundant in Lake Keokuk, will regain the former status in the upper river, either by local propagation or by invasion from below.

From the figures brought together by Oscar E. Sette (1925, p. 209), it appears that the paddlefish, after a marked decline following the census year of 1899, has been holding its own as a commercial resource of the Mississippi Basin generally (not considering any particular part of the basin).

Below is shown, in pounds, the product of the paddlefish fisheries of the Mississippi River and tributaries (not including the Atchafalaya) for various years:

	Pounds
1894	1, 028, 445
1899	2, 473, 250
1903	1, 421, 086
1908	1, 439, 000
1922	1, 328, 991

SUMMARY

The paddlefish, though not looming relatively large in the product of the commercial fisheries of the basin, is, pound for pound, one of the most valuable fishes of the region. Formerly sold under a false name, it has now come to stand upon its own merits. Furthermore, its roe has a fancy value for the production of caviar. The breeding of paddlefish has never been observed but is presumed to occur in early spring.

Soon after the construction of the dam there was evidence of a marked decline of the fishery above the dam, with later suggestion of partial recovery. The recovery, particularly notable in Lake Keokuk, has been more marked in recent years, and there is little doubt that paddlefish are now self-propagating in the lake and are finding there favorable conditions for growth. From the time of construction of the dam up to 1926 paddlefish with broken snouts have been seen not infrequently in the river just below the dam; the precise origin of the injuries can not now be fixed. It has been shown experimentally that paddlefish can pass through the turbines or over the spillways without suffering such injury, but this does not prove that injuries may not be incurred in such passages.

THE STURGEONS (Acipenseridæ)

Among the most valuable of all fresh-water fishes are the representatives of the sturgeon family. These are esteemed for the staple food their bodies afford and for the high-priced delicacy prepared from their large eggs. The swim bladders of sturgeons are also useful for the preparation of fish isinglass. Like the paddlefish, the sturgeons are large in size but peculiarly inoffensive to other fishes. Their toothless jaws prohibit their deliberate preying upon their neighbors, and the only damage they can do is through participation in the general competition for small articles of food or the occasional sucking in of small fish and eggs along with the bottom material and organisms that seem to constitute their habitual diet. Again like the paddlefish, they have displayed wonderful abilities to survive through long ages the physical vicissitudes of the earth, while they have shown little power to resist the destructive activities of modern man in America. For we in America, it must be admitted, have been much more successful than the Russians and other Europeans in the destruction of the valuable sturgeon. Notwithstanding the long history of the sturgeon fishery

of eastern Europe, great fisheries still exist there, and consequently we import the greatest share of the caviar that we consume, although we have native sturgeon on both seacoasts, in the Great Lakes, and in our large rivers.

In America we have two general types of sturgeon, which might be distinguished roughly as conical-nosed and flat-nosed. All the sturgeons of the Atlantic and Pacific coasts (as well as those of Europe and some in Asia) belong to the first group, having a relatively short snout, rounded above, though flat underneath (something like a half cone), with spiracles on top and having a relatively stocky and rounded tail not completely surrounded by protective armor of bony plates. Of this type there are five American species—two upon each major seacoast, Atlantic and Pacific, and one that we know as the lake sturgeon in the Great Lakes and upper Mississippi Valley. The other type is without spiracles and has a shovel-shaped snout and a long, flattened,

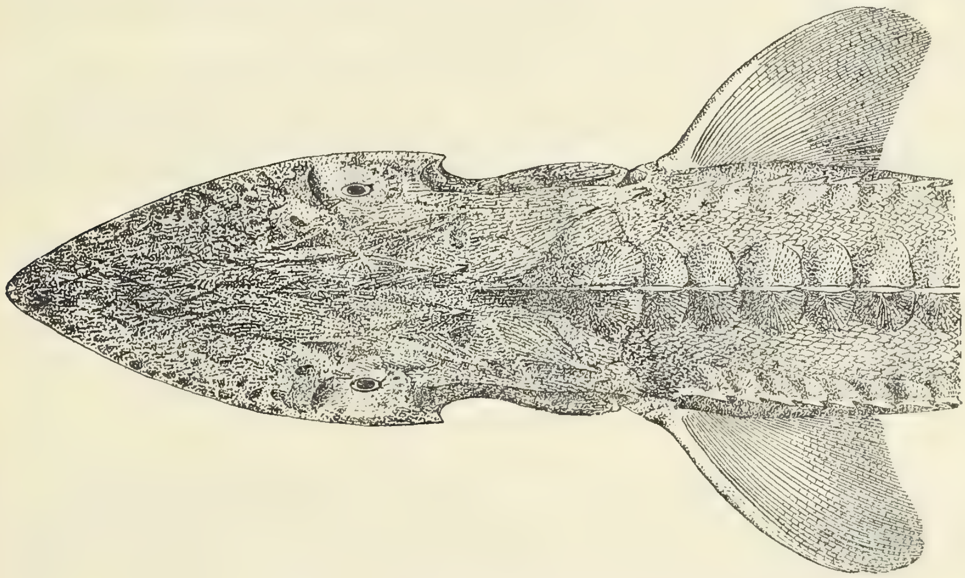

FIGURE 2.—Head of a shovelnose sturgeon, *Scaphirhynchus platorhynchus*

and completely armored caudal peduncle (the "tail," excluding the tail fin). We have seen that the paddlefish has but one near relative and that is found far away in a great river of China. So with the shovelnosed sturgeon, its only really close kin (of the same or a closely related genus), besides one rare species in the same basin, are several species found in central Asia. (Berg, 1904.)

Sturgeons are as toothless as their ancient comrade, the paddlefish, but they do not, like that fish, feed by charging through the water with widespread mouth to filter innumerable small organisms. Instead, they are said to lumber about sluggishly, thrusting out their very protrusible lips to suck in mud or small organisms that they find on or near the bottom. They are not ordinarily addicted to swift waters, and if other conditions are found favorable the impounding of river water is not in itself unfavorable to them.

Lake sturgeon. *Acipenser rubicundus* Le Sueur [4]

ROCK STURGEON; RUBBERNOSE STURGEON

The lake sturgeon, though formerly abundant in all the Great Lakes region and the Mississippi Basin, has for a long time been in process of extermination owing, in the first instance, to wasteful destruction by fishermen in past years when no use for them was known and they were regarded only as unmitigated nuisances if captured in trap nets or seines.[5]

The lake sturgeon attains a size of about 6 feet in the Great Lakes. There are reports, indeed, of 9-foot sturgeon, but the average length of mature fish is less than 5 feet. (Milner, 1873.) The food, according to many observers, consists of small shellfish, gastropods (Milner), crawfish (Smith, 1892), insect larvæ (Woolman; see Evermann and Latimer, 1910), larvæ of May flies (Wagner, 1908), and worms (Ryder, 1890). Fish eggs have been found in the stomachs, but not frequently, and the eggs observed have been mostly eggs of the sturgeon.

All observations indicate that lake sturgeon approach the shores and ascend smaller rivers at the spawning season, which in the more southern of the Great Lakes occurs in the month of June. When in the spawning migration they frequently "break" the surface and even leap entirely clear of the water. (Milner, 1873.) The

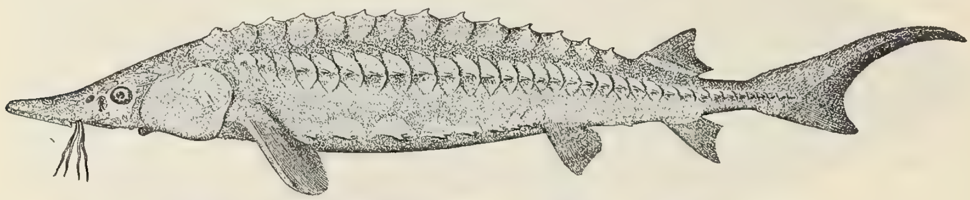

FIGURE 3.—Lake sturgeon, rock sturgeon, or rubbernose, *Acipenser rubicundus*

large eggs are strongly adhesive. Up to the present time very slight success has rewarded the many efforts that have been made to apply methods of artificial propagation, not only because the eggs are troublesome to handle but also because almost invariably great difficulty is encountered in securing ripe fish of both sexes at the same time. Barney (1924) has suggested that the lake sturgeon does not spawn yearly but has an extended reproductive cycle, since most of the adult fish caught in Lake Pokegama, Minn., during the breeding season were unripe.

As concerns the Mississippi River in the section near and above the Keokuk dam, Forbes and Richardson (1908, p. 25), writing in 1908, five years before the construction of the dam, said:

> Lake sturgeon have of late years been steadily decreasing and are now only rarely taken in the Mississippi on our own borders (those of the State of Illinois) and are seldom caught in Illinois. Fishermen at Alton now see but 5 or 6 a year that weigh over 10 pounds, whereas 15 years ago 40 or 50 large ones, weighing from 50 to 100 pounds, were taken each season.

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[4] Hubbs (1917) suggests that the name *Acipenser fulvescens* has priority over *rubicundus*. However, as Rafinesque gives no recognizable description of the species that he designates *A. fulvescens*, we think the suggestion should not be adopted. Identification of Rafinesque's species can be made only on the assumption that no other species of sturgeon could have been at the place where he collected an assumption that may be true but that clearly does not admit of scientific determination.

[5] Meek (1890) says (for Iowa): "The species is common in the Mississippi River in the spring; rather scarce at other times of the year." But, again, referring to the same observations, he says in 1892 (p. 221): "Not common; more abundant in the spring." He knew of no postive record for any other stream within the State. Woolman (1892) describes the lake sturgeon as common in the lower parts of the Cumberland and Tennessee Rivers, while Evermann (1902) says the rock sturgeon "does not appear to be common anywhere in the Ohio Basin."

We therefore have little concern with the species in this report, except in so far as a discussion of its decline in Lake Pepin is necessary to an understanding of changing conditions of the fishery and of resources generally in the upper Mississippi River.

Wagner, writing in 1908, says of the lake sturgeon or rock sturgeon in Lake Pepin (1908, p. 31):

> Pound for pound, this is the most valuable fish marketed by the seiners. Large specimens have become scarce, however, in late years, so that 12 or 15 in a season are considered a good catch. Smaller ones up to 50 centimeters (20 inches) in length are not uncommon.

H. O. Hesen, superintendent of fish culture at the Fairport station, showed me a small rubbernose sturgeon collected by Otto Stumne in Lake Pokegama, Minn., July 14, 1925. It had a total length of 19 centimeters (about 7½ inches) and is probably one of the smallest examples of record.

Pearse (1921, p. 12), writing of the same lake, says: "In 1920 the hackleback was abundant and the rock sturgeon (not seen by the writer) very rare." On September 3, 1921, the present author was informed by the operator of a large seine near Lake City, Minn., that he had taken only one rock sturgeon that year.

While a decided increase in the commercial catch was reported in 1922, it may be observed that the increase was in direct ratio to the increase in catch of all species. In 1926 all reports indicated continued scarcity of the fish in that part of the river, and none were reported in the canvass for 1927. They are known, however, to be not uncommon in Lake Pokegama on the Snake River, a tributary of the Mississippi in Minnesota, and reports are received of good catches in the Wisconsin River. The condition of the water of the Mississippi River must, therefore, be taken into account in considering the causes of scarcity in that stream.

It is of interest to note the conditions that, as early as 1871, were leading to the depletion of sturgeon resources in some of the Great Lakes. James W. Milner made an investigation of the fisheries of the Great Lakes in 1871. He relates (1873) that the sturgeon taken abundantly in the pound nets were drawn out with a gaff hook and either let go wounded or thrown on the refuse heap. The same author tells of the netting of sturgeon at Sandusky, where "the sturgeon taken by the nets were (formerly) uselessly destroyed or sold by wagon load for a trifle." A few years before his investigation a firm had established itself at Sandusky both to prepare caviar from the roe and to smoke the meat of the sturgeon. About 14,000 mature sturgeon averaging less than 5 feet in length and about 50 pounds in weight were handled by them in 1872—"out of a shameful waste of a large supply of food they have established a large and profitable industry."

But, whether wasted or utilized, the lake sturgeon, like others of the rivers and the seacoasts, has been unable to withstand the effects of our fisheries. They have other enemies, such as the fishes that may destroy their spawn and the lampreys, which attack sturgeon of all sizes, but the armor of plates and spines makes the sturgeon, even in young stages, relatively immune to attacks from other fish with which they have lived through thousands of years. It is evident, therefore, that their principal enemy and the chief cause of their decrease in numbers has been man.

On April 3, 1915, Williams Jobe, using a trammel net below the mouth of the Des Moines River, captured a lake sturgeon 57½ inches in length. It weighed about 47 pounds when caught and 22 pounds dressed. The roe weighed 11¾ pounds. The stomach was empty. Another, 39 inches long and about 14 pounds live weight, was taken by him on February 16, 1916. These were the only captures of lake stur-

geon in the vicinity of Keokuk that came authentically to our attention during the investigation.

In 1926 we were informed of occasional catches of rock sturgeon in the lake. Mr. Brusor at New Boston, said that in 1925 he had taken one weighing 109 pounds; this and two or three small examples were the only ones he had seen in several years. Somewhat similar reports were received from others. A fisherman at Canton, Mo., 22 miles below the dam, said that small rubbernose sturgeon (about 15 pounds) were not infrequently taken in the spring.

Shovelnose sturgeon. *Scaphirhynchus platorhynchus* (Rafinesque)

HACKLEBACK

The common sturgeon of the Mississippi in the region affected by the Keokuk Dam is the shovelnose sturgeon or "hackleback," *Scaphirhynchus platorhynchus* (Rafinesque), a species that is generally common in the larger rivers of the Missisipi Basin. It does not attain a large size. Specimens seen in the markets are usually 2 feet or less in length, but these are no doubt undersized. At Fairport, Iowa, the average weight is said to be about 3 pounds, but 6-pound sturgeon are mentioned. Evermann (1902) said that the largest he had ever seen was under 4 feet. Little is known of the habits of this sturgeon. Evermann stated that it swims well toward the surface when running and is taken along with Ohio shad and paddlefish. In the Mississippi River, however, it is usually taken near the botton in drifting trammel nets leaded to drag on the bottom; some are captured on trot-lines baited with minnows or worms.

The fate of the sturgeon in the Mississippi is one of the tragedies of shortsightedness in the conduct of the fishery. Only a few years ago this fish was considered almost worthless and, when taken in the nets, was regarded by the fisherman as a nuisance; the labor of skinning them was not compensated for by the price obtainable. All testimony indicates that it was the common practice to break the necks of the sturgeon when caught or to throw them high on the bank to die. Sometime within the first decade of the present century the value of the roe for caviar and the profit in handling "hog-dressed" fish for smoking were first appreciated in a general way. Previously a few had been sold in local markets, but virtually none had been shipped. The hackleback is now one of the most esteemed of smoked-fish products from the Mississippi and is commonly seen in all the local markets. It is prepared by the practice of "hog dressing," that is, removing the entrails but leaving on the skin and scales. The roe is of high value, but statistics of the fishery indicate that, on the whole, the meat brings a greater return to the fisherman than does the more intrinsically valuable roe.[6]

The shovelnose sturgeon is said to spawn in the spring, probably ascending the smaller streams for that purpose (Goode, 1884, p. 663; Kirsch and Fordice, 1890, p. 247; Forbes and Richardson, 1908, p. 27), but no record of observation has been found. An example was collected in Louisiana in winter (Jordan 1884a, p. 318), but the species was not noted during an investigation conducted in April and early May (Evermann, 1899); possibly this was due to chance or to the fact that collections were not made at a breeding place. Trumer Jackson, of Warsaw, Ill., who formerly fished at Cairo, about 300 miles south of Keokuk, stated that the fish, though regu-

[6] On July 3, 1917, the price of sturgeon meat at Keokuk was 16 cents while the price of sturgeon roe was $2.75 per pound. The price varies greatly, being influenced by importations of Russian caviar; it may be as low as 50 cents a pound.

larly taken there, do not have eggs large enough for caviar. About Keokuk it is found with eggs suitable for caviar from late summer or fall until early June.[7] In 1915 the last can of caviar was shipped from Warsaw on June 7, but the eggs may have been taken several days earlier; in 1916 the last shipment was made on June 13. In the latter year a small shipment was made from Canton, Mo., on June 21. The fish itself continues to be taken in substantial though lessened numbers for another month.

Luther McAdams, of Keokuk, names May 10 as the height of the season for eggs of sturgeon. At about that date, using heavily loaded trammel nets drifting in the "channel lick," about 1.5 miles below the bridge at Keokuk, he has taken sturgeon in quantity with eggs and milt flowing from them as they were removed from the net. The nets were dragging the bottom, as evidenced by the fact that small rocks in numbers were caught in the pockets of the net.

The sturgeon was about fourth in abundance among the fish found immediately below the dam by Surber in 1913. (Coker, 1914, p. 10.) This was a month after the end of the spawning season. Such degree of abundance is not remarkable. The two principal dealers at Keokuk and Warsaw stated that the fish had been commoner after than before the erection of the power station. Surface observations are of no significance because the fish is of bottom habit and rarely seen at the surface; the author has never seen it free in the water. In the immediate neighborhood of the power plant, according to our observation, it is infrequently taken, although set lines are used there regularly; near the dam an example was caught in a trammel net on June 22, 1915, and another in a gill net on May 30, 1916. Three-quarters of a mile to a mile (1½ kilometers) below they were caught in set lines. From here to Warsaw the principal fishery existed, being prosecuted with trammel nets drifted in the current. Of all the recorded catches of fish about Keokuk, 11 contained this species, and all of these but one were products of the trammel net. The capture of a specimen in a slough (behind Mud Island) excited the interest (June 25, 1915) of the fishermen because the species is virtually never taken except in the river. It is known as a fish of the current.

Examples were seen about Keokuk during the years 1915, 1916, or 1917, in each month from February to September, inclusive. Dealers and fishermen said that it was occasionally taken in quantity during the winter. When weekly inquiries of the markets were started the season was almost ended; the quantities reported by the three markets, given to the nearest hundred pounds, are shown in Figure 4.

The "hackleback," as it is appropriately called, is reported to be less abundant on Keokuk Lake than it used to be on the river. The commercial yields of hackleback from Lake Keokuk in all years of the survey were insignificant, being 1,900 pounds in 1914, 454 pounds in 1917, 600 pounds in 1922, and none in 1927. Monthly inquiries during the open season of 1916 showed that from 100 to several hundred pounds a month were taken at Burlington. At Fort Madison, where the current is slight, a few were taken, but never as much as a hundred pounds in a month. Farther down, at Montrose, Iowa, the fish is rarely taken, no instance having come to the attention of the writers. These facts reflect the strong preference of the species for a current. All reports in 1926 indicated scarcity of hackleback in the lake and the river immediately above. George E. Smith, at Fairport, said in 1926 that there were still seasons of plenty and seasons of scarcity, but he believed that on the whole sturgeon were on

[7] George E. Smith, at Fairport, said that sturgeon with roe suitable for caviar are taken in fall, winter, and spring.

the decline. The only evidence to suggest the maintenance of the species in the upper river is the increasing abundance of the egg mussel ("glassy-back" or "Missouri niggerhead," *Obovaria ellipsis*); the only fish now known to carry that mussel in its parasitic larval state is the shovelnose sturgeon, although there may be other hosts that have not been detected.

The run of sturgeon in the river below Keokuk is said to be very variable; a good run is expected when the river is low during the spring, as in 1925 and 1926, when the expectations were fully realized. High water is said to be unfavorable. After the spawning period the fish continues to be taken in considerable but decreasing numbers,

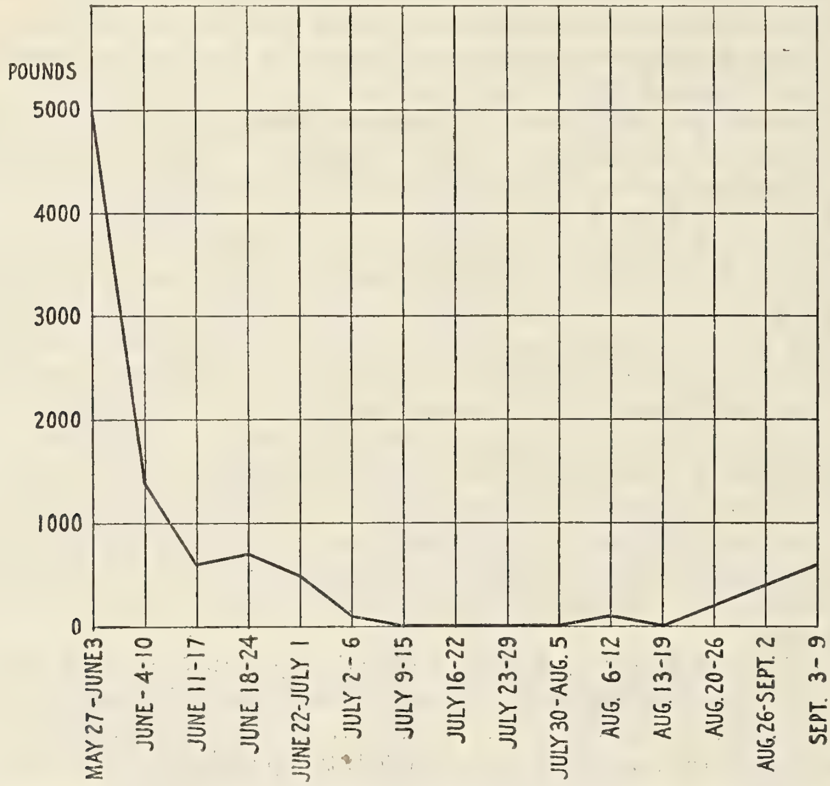

FIGURE 4.—Quantities of shovelnose sturgeon taken near Keokuk, Iowa, by weeks, May 27 to September 9, 1916

indicating that it spawns in this vicinity and then drifts southward, though probably some remain all year. For 1922, 1,080 pounds of shovelnose sturgeon were reported from Lake Pepin, but the fish has always been rare in that lake.

That propagation now occurs above the dam is attested by the fact that very small sturgeon have been taken in the river at Fairport, Iowa, on several occasions. The Fairport station now has examples measuring in standard lengths, respectively, about 2 inches (52 millimeters, taken in July or August), 2.8 inches (71 millimeters, taken July 11, 1919), and 4.6 inches (116 millimeters), all taken at Fairport.

White sturgeon. *Parascaphirhynchus albus* Forbes and Richardson

This species is relatively rare, and virtually nothing is known of its habits. Local fishermen report taking them not infrequently, and say that they rarely contain

visible eggs. An example taken near Keokuk on April 21, 1916, measured 69 centimeters (about 28 inches), 55.5 centimeters to base of caudal fin, and weighed 0.75 kilo (about 1½ pounds). The stomach, examined by Stringham, contained about a cubic centimeter of matter, consisting of insect débris (90 per cent), May-fly remains (5 per cent), and parasites (5 per cent). In the intestine were about 3 cubic centimeters consisting of fish (minnows 95 per cent) and May-fly nymphs (5 per cent).

SUMMARY AND CONCLUSION REGARDING STURGEONS

The rock sturgeon or rubbernose sturgeon was formerly a fairly abundant fish in the upper Mississippi River and of the highest value for its meat and roe (for caviar). It has now been virtually lost as a commercial fishery resource, but it would be impossible to connect its disappearance with the Keokuk Dam, inasmuch as the fish had been virtually lost to the middle section of the river at least five years before the building of the dam. It has also been lost to the fisheries of the Great Lakes.

The shovelnose sturgeon or "hackleback" is a small but very valuable fish. It makes the most generally esteemed smoked-fish product of the river, and its roe sells at a high price for production of caviar. It frequents regions of strong currents and swims near the bottom. Its breeding habits have never been observed, but in the vicinity of Keokuk the height of the spawning season is evidently in May, and reports indicate that spawning occurs on rocky bottom in swift water. The fish does not frequent still waters in numbers, and it is not now known to be abundant anywhere above the dam. Its abundance in the river a short distance below the dam seems unaffected. Its preference for current virtually eliminates it from Lake Keokuk or Lake Pepin. As regards the river between these lakes our evidence is hardly adequate but, as far as it goes, indicates a declining importance of the species in that region. Evidently, however, breeding occurs in the river above the dam. Further inquiries should be made during a season of good flow of water.

The white sturgeon is little known and is apparently of small commercial importance in the river.

THE GAR PIKES (Lepisosteidæ)

With the gars we come to another small group of fishes that is peculiarly North American. Reptilelike, flexible-bodied, air breathers, heavily armored, formidably toothed, they are so distinctive in appearance that everyone knows them. They are sluggish but powerful, stealthy but voracious. They are widely distributed and almost universally regarded as unmitigated nuisances. It can not, however, be said that they are universally despised, for the meat of gars is said to be esteemed by negroes and to have been a common food of Indians. Some white persons who have eaten the meat describe it as white, well flavored, and wholesome; others find it coarse and stringy. Possibly the ill favor with which it is generally regarded as a food fish by whites arises, as in the case of eels, from some suggestive features of its appearance more than from intrinsic qualities. The roe of the female, although made up, when mature, of large eggs that might be expected to be useful as a fresh food or as caviar, is said to be decidedly toxic, and it may therefore be that unpleasant experience from the use of the roe has had something to do with the establishment of a firm prejudice against the meat. Whatever may be the future place of the gar in dietetics, it is at present to be regarded as a generally unwelcome element of the fauna of the river. Nevertheless, any influence of the dam upon their numbers would be a proper

subject for consideration, even were they not, in one respect at least, useful agents in the larger rivers.

It may surprise most people to be told that the gar serves any useful purpose, but the interrelations of nature give frequent occasion for surprise. Within comparatively recent years it has been learned that the gar serves as the host of the parasitic young (glochidia) of the most valuable of all fresh-water mussels. (Howard, 1914.) The yellow sand shell (*Lampsilis anodontides*) yields a shell that for form, texture, and luster compares most nearly, of all fresh-water shells, with the marine "mother of pearl." It is useful not only for the manufacture of buttons of superior grade but also for the preparation of pearl handles for knives and for other novelties. From extended investigation, it appears that all species of gar may function as hosts of this mussel, and that no other fish will answer. Without the presence of gars in our rivers we could not have a fishery resource that has considerable present value and doubtless greater future value, unless this mussel can be maintained by artificial means.

The most striking feature of change in the fauna of the upper Mississippi in the last dozen years is the great increase in the numbers of yellow sand shells. From being a very infrequent shell culled out in small quantities to be exported for the production of novelties, it has now become a standard shell for use in button manufacture, yielding a high price because its elongate form, relatively uniform thickness, and good cutting qualities permit a high-quantity production of buttons. To a considerable extent it now replaces the niggerhead mussel, once the standard shell for button manufacture. The clammers of the river are now beginning to hold the gar in higher esteem.

Some notes regarding the habits of the gars will establish more clearly their place in the biological economy of the river.

More than other fishes, the gar is commonly in evidence, owing to its habit of swimming at the surface. Equipped with a cellular air bladder, which functions in part as a lung, the gar frequently "breaks" the surface, protruding it head and long snout, turning partly on its side, emitting a bubble of exhausted air, and gulping in a new supply. "The movements are very rapid and almost convulsive, as if the fish were suddenly oppressed by something and hastened to remove it." (Wilder, 1877, p. 7.) Garman found that when a gar was restrained below the surface air bubbles were allowed to escape and the fish became evidently very uneasy, "moved rapidly to and fro, turned and twisted and lashed its tail," until it was permitted to rise to the surface, when it apparently gulped in a large volume of air. After this it descended and remained quiet for the usual period. Mark (1890) concluded from his experiments that only oxygen exchange with the atmosphere was effected in this way, the respiration of CO_2 being effected in some other way; but Potter (1927) has recently shown that both oxygen and CO_2 exchanges take place through the swim bladder. Furthermore, Potter gives evidence to indicate that "the capacity of the swim bladder and the rate of inhalation are great enough to supply sufficient air for the needs of the body." It appears that gar pikes have alternate modes of respiration—by gills or by the swim bladder functioning as lungs—and that they will live for days when forced to depend exclusively upon either the one or the other.

"The manner of feeding is also unlike that of fishes and resembles that of reptiles. Other fishes take their food with open mouth and swallow it at once; but this one approaches its prey slyly, sidewise, and, suddenly seizing it, holds it in its jaws until

by a series of movements it succeeds in getting it into a proper position for swallowing, as is the habit of alligators and lizards." (Agassiz, 1859, referring to young gars.)

They are voracious from an early age. Forbes and Richardson found 16 minute minnows in the stomach of a long-nosed gar only 2 inches long and one-eighth inch deep. Others had small Cladocera. Mark (1890) regarded small insect larvæ (mosquito larvæ) as the principal food of very young gars.[8] All other observers agree that fish are the principal food of older gar pikes. Pearse, from observation in Madison Lake, Wis., found that fish comprised nearly 90 per cent of the food of 10 specimens examined. (Fish, 88.8; insect larvæ, 10.2; adult insects, 1.) Stringham (in connection with this investigation) noted the stomach contents of 20 examples of long-nosed gar taken at Keokuk; 9 contained nothing, 9 contained fish (one of these having a minnow and an insect larva), and 3 contained insect larvæ. He also observed the stomach contents of 41 short-nosed gar, 27 of which were empty, 6 contained fish, 4 insects, 1 crawfish, and 3 undetermined matter, apparently straw and seed. These are apparently the first recorded observations of the food of this species of gar.

While the food of gars is chiefly fish, there seems to be no record of their preying upon game fish. No doubt they do, but their injurious effect upon other fishes is probably based primarily upon their effective competition with other predatory fishes for the limited food supply.

The gar of the Mississippi Basin are variable in appearance and there has been some difference of opinion as to the number of species. According to common usage, there are three species in the United States [9]—the long-nosed gar or billfish, the short-nosed gar, and the alligator gar. The last-mentioned fish, which is said to attain a length of 20 feet, probably never ascends the Mississippi far above the mouth of the Illinois River and may be excluded from consideration. These three species comprise the sole representatives of a family that seems to have thrived at least as far back as the Carboniferous age, if not earlier. The genus Lepisosteus goes back to early Tertiary times. To-day it is found only in North and Central America and in Cuba. In the United States gar pikes are found in the Atlantic, Gulf, Mississippi, and Great Lakes drainages. The restricted distribution of the family is the more remarkable since the gar pikes are not altogether averse to salt water. (Smith, 1907, p. 59.) Their distribution indicates that they can withstand both high and low temperatures, although they are active only when the water is relatively warm. In cold weather the habit of coming to the surface is discontinued, and the fish remain below in a dormant or benumbed condition. Their strong armor protects them effectively against the depredations of other fishes.

Long-nosed gar. *Lepisosteus osseus* Linnæus

BILLFISH

The long-nosed gar is the most widely distributed species, occurring throughout the Mississippi and Great Lakes drainages, on the Atlantic coast, and even in Mexico, and frequenting the larger streams or sluggish waters. Most of the observations that have been published on the breeding habits of gar pike probably relate to this species.

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[8] Apparently they will not bite at any object unless it is in active motion. They will, however, sometimes push an insect larva about until it demonstrates its vitality by actual motion, when it will be snapped up by a sideward movement of the bill. (Mark, 1890.)

[9] Fowler (1910), from study of museum collections, has proposed a number of species and a new genus. An account of the distribution of the several species is not attempted. His paper was not available when our observations were made, and we can not relate our observations to his diagnoses.

It frequents shallow water for spawning, depositing the eggs in grass or weeds or about stone piles (Forbes and Richardson, 1908, p. 33), the season of spawning in the United States being about June 1.[10] The eggs are apparently adhesive, becoming attached to stones or other objects. After hatching the young attach themselves by means of maxillary disks; they may suspend themselves from the surface film. (Mark, 1890.) "They are extremely interesting and even beautiful little animals, each marked with a broad black lateral band; they are especially noticeable for the evanescent lance-shaped upper lobe to the caudal fin." (Forbes and Richardson, 1908, p. 33.) The food of the young seems to consist of insect larvæ, Entomostraca, and very small fish, making them serious competitors if not direct enemies of the young of useful

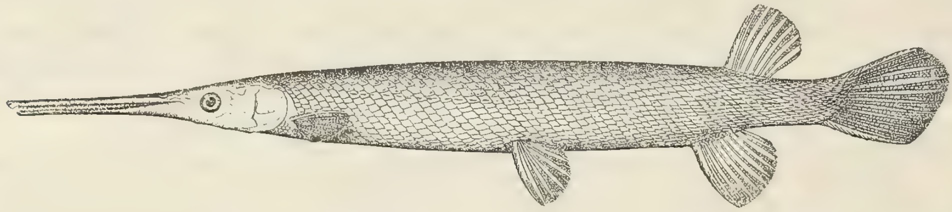

FIGURE 5.—Longnose garpike, *Lepisosteus osseus.* (Specimen from Florida)

fishes. Garman (1890) found, near Quincy, Ill., young long-nosed gar measuring 6 to 12¼ inches in length, the average length being 8.1 inches. Presumably they were gar of the season.

The long-nosed gar seems virtually unknown in Lake Pepin (Wagner, 1908), and it is much less common in the vicinity of Keokuk than the short-nosed gar, to which our observations chiefly relate. The two seem not to be essentially different in habit, and the discussion may apply equally well to both species.

Short-nosed gar. *Lepisosteus platostomus* Rafinesque

DUCK-BILL GAR

The short-nosed gar occurs throughout the Mississippi Valley, being the more common species in the vicinity of Keokuk. The two species are readily distinguished

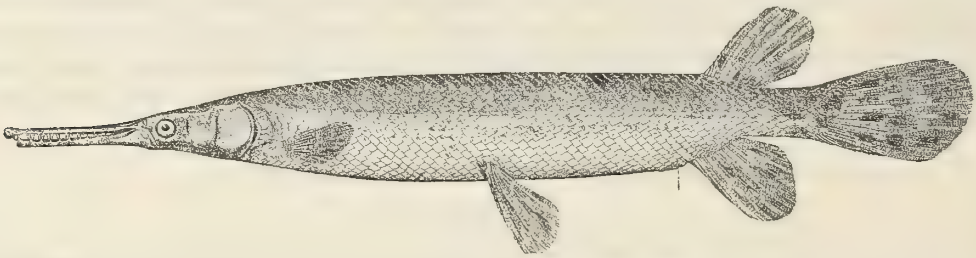

FIGURE 6.—Shortnosed gar, *Lepisosteus platostomus*

by the form of the beak, which in the long-nosed gar, according to observations by Stringham at Keokuk, is 14.5 to 20 times as long as the least width (average 16.7), while in the short-nosed gar the length varies from 5.7 to 7.4 times the least width (average 6.5).

Richardson (1913a) found the breeding season in the vicinity of Havana, Ill., to be from the early part of May to the end of June at least. (In 1899 spawning con-

[10] Evermann (1899) records the capture of a spawning female taken at Morgan City, La., on Apr. 23, having a standard length of 40 inches, weight 9 pounds, weight of ovaries 19 ounces, and number of eggs 36,450.

tinued until August. Forbes and Richardson, 1908.) The fish ran in pairs, each female with a smaller male, spawning in shallow water full of weeds or willows. The eggs adhered to grass and smartweed; they were found attached even above the surface of the water, and some of these hatched.[11] The eggs hatched in about eight days. The young were solitary in habit, being found always floating at or near the surface in the sun, sometimes with the back out. Young 3½ inches long were taken on July 7. Garman (1890) had found, in the vicinity of Quincy, Ill., in August, young short-nosed gar up to 12.5 inches in length, the average of 18 examples being 9.94. A rapid rate of growth in early life is indicated.

The adult gars are said to move in large schools both before and after the spawning season. The distribution of gar pikes indicates that breeding occurs in northern and southern regions, and there is no evidence that extensive migrations are necessary for reproduction.

In the vicinity of Keokuk the short-nosed gar is one of the most abundant fishes, being rivaled by the German carp, the river quillback (*Carpiodes carpio*), and two species of minnows. It is, of course, much in evidence from its surface-swimming habit. Adult fish were found everywhere below the dam and lock, in the river, sloughs and creeks. Many fingerlings were seen in 1916 near the lock, both above and below.

The inclosed portion of the unfinished part of the power house formed, in effect, an imperfect trap about an acre in extent, in which great numbers of gars were observed in 1915 and larger numbers in 1916. Observations in 1915 indicated that the aggregation of gars in the space corresponded roughly with the stage of the river. When the level of the river was above the top of the walls of the inclosure, or much below it, the aggregations were not noted; presumably the gars escaped, in the one case over the top of the wall and in the other through the submerged openings, which were nearer the surface at low stages. No correlation with breeding season could be noted. The times when aggregations were noted in 1915 were as follows: May 17–26, June 18–July 9, July 17–24, August 10–27, and September 15. Breeding was over by the end of June, as indicated by the examination of fish in July and later.

While generally reported as abundant in Lake Keokuk in 1926, the reports of fishermen were far less strong regarding gar in the lake than in the river; the gar is "more for current," some said. Nevertheless, it is extremely abundant in Lake Pepin. Several hauls were witnessed, and gar far outnumbered all other fish combined, although gars are particularly successful in escaping the net. Reference has previously been made to the remarkable increase in numbers of yellow sand shells, a mussel that is aided in propagation by the gars. This does not necessarily indicate an increased abundance of the fish, for there are other conditions that seem increasingly favorable to the survival and growth of yellow sand shells, to be discussed later.

There are, of course, no commercial figures concerning the gar pikes, but their continued abundance in the upper river is unquestioned. The lake probably offers suitable breeding places for them, but in 1926 it appeared that gar were relatively less abundant in the lake than in the river above and below. Presumably the gar pike is so well able to take care of itself under most varied conditions that the river will continue to be as abundantly stocked as the condition of the food supply and competition permit.

[11] H. L. Canfield found eggs of the gar adhering in quantities to flood trash on the banks of the White River near Clarendon, Ark.

Bowfin. *Amia calva* Linnæus

DOGFISH; MUDFISH; GRINDLE; LAKE LAWYER; ETC.

This odd fish is called by a dozen names, none of which probably is intended to be complimentary. In the classification of fishes it stands quite alone as the sole living representative of an order (the Cycloganoidea) with some characters regarded as most primitive and others as fairly modern. The swim bladder has a cellular structure, opens into the esophagus, and functions as a lung, aiding the gills in respiration. Its double respiratory apparatus makes the fish adaptable to a variety of conditions. It can live in lakes and rivers, in ditches and rain barrels. Live bowfin are said to have been plowed up in lowland fields of Louisiana some weeks after the subsidence of floods and the drainage of the land sufficiently for cultivation. It prefers sluggish waters and is not common in the river below the dam, although it occurs there. It is apparently quite common in the back waters of the lake, for the author was told on September 24, 1917, of a catch of 1,500 pounds of bowfin in two hoop nets set in Green Bay. In that year there was a very good winter demand for bowfin in the markets of some of the larger cities, but the summer price was low

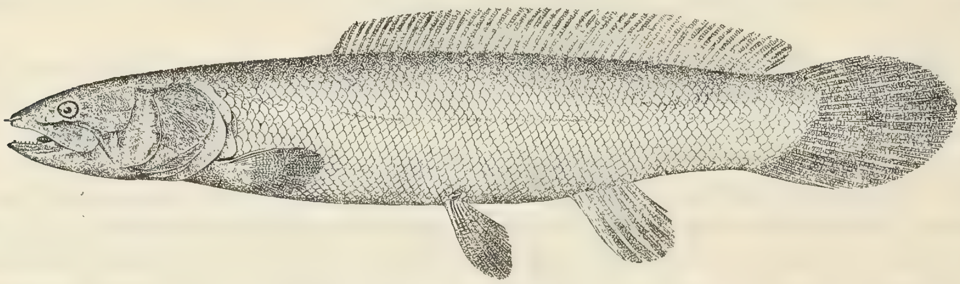

FIGURE 7.—Bowfin, *Amia calva*

because the fish had to be retained in cribs constructed for the purpose near the shores of the lake. It was an interesting fact that great quantities of live bowfin could be retained for months in small cribs at Dallas City. The owner said that the secret of keeping bowfin was to put in a few carp—the sluggish bowfin alone would settle thickly on the bottom and smother each other, but a few carp would keep the mass of fish stirred up so that all remained alive for a long time.

At the beginning of this investigation the bowfin was generally held in the lowest esteem as a food fish; its soft, pasty flesh renders it unfit for use unless prepared in some special manner, as by stuffing, seasoning, and baking. Strange to say, when properly prepared by smoking it makes one of the best of all smoked fishes. Partly, no doubt, as a result of educational work conducted by the United States Bureau of Fisheries, after experimental work at the Fairport station, there has developed a good demand for the fish in the markets of several cities. The bowfin, therefore, is no longer to be disregarded as a food fish.

It is unattractive in appearance and very predaceous, and these qualities loom largest in popular thought regarding the fish. It has strong sharp teeth and is said to bite a 2-pound fish in two at a single snap. Its food, as observed by Forbes and Richardson (1908), is about one-third fish (minnows, buffalo fish, etc.), about one-fourth small mollusks, and the remainder crawfish. Insects form a very small proportion of the food. Pearse (1918) examined 14 specimens from lakes near Madison,

Wis., and found a much higher ratio of fish to other food—fish remains 96.6 per cent, and crawfish remains 3.3 per cent. It is in any event a severe competitor to more esteemed fishes. It is a strange corollary of our prevailing schemes of conservation of fish that destructive species such as the bowfin are rather rigidly although unintentionally protected in many waters where, in the supposed interest of angling, prohibitions are imposed against the only methods of fishing by which the numbers of bowfin and other "coarse fishes" can be reduced effectively; that is, against the use of nets.

A lover of sluggish waters, the bowfin is abundant in the Great Lakes region, in the Mississippi Valley from Minnesota to Louisiana, and in the east from New York to Florida. It seems to like the weedy waters, frequenting shallows at night and returning to deeper places by day. In some places it is taken at night with jacklantern and spear. In winter they have been found closely huddled in gravelly pockets among water weeds. Nesting, as observed by Reighard and others, takes place in quiet shallow places among vegetation, stumps, roots, and logs, the male guarding the nest and protecting the young, which move in schools until they are about 4 inches long.

Under the conditions of our observations very few bowfin were observed, but we know of their presence in the lake and its environs, and it seemed a reasonable presumption that the sluggish backwaters, with their weeds and brush, would be favorable to the production of bowfin. The catches of bowfin in the four years of statistical canvass of Lake Pepin were 1,534 pounds in 1914, 2,402 pounds in 1917, 16,136 pounds in 1922, and 3,334 pounds in 1927. For Lake Keokuk the fish was reported only in 1917 (26,000 pounds) and in 1927 (14,055 pounds). In the case of this fish irregularities in commercial yield might reflect only fluctuations of demand, but it was the common report of fishermen in 1926 that "dogfish" were not very abundant in the lake or in the river, although still taken and marketed principally in the spring. One chief source of supply in 1917, Green Bay, was eliminated by drainage in 1919. From all we know of the habits of the bowfin, the dam could have no deleterious effect upon its propagation. Perhaps it was never so numerous as some have supposed; it would seem more abundant when regarded as a nuisance than when in some demand. The weightiest testimony as to diminution of bowfin comes from trotline fishermen of the lake and of the region of Fairport to the effect that large schools of "dogfish minnows" can no longer be found for use as bait.

THE HERRINGLIKE FISHES

Under this head we are concerned at Keokuk with a true shad, a herring or alewife, the gizzard shad, and the mooneyes. Following the systematic order, we consider first the mooneyes—silvery, herringlike fishes, of which there are two species that occur in the Mississippi Basin from the Ohio River northward and also in the Great Lakes region and the Saskatchewan.

Nowhere do the fishermen appear to distinguish the two species, which are, however, rather readily recognizable. Dr. Franz Schrader, while an investigator for the Bureau of Fisheries, observed that although both species have a tint of gold in the eye the larger species (*alosoides*) has a pronounced ring of gold where only a portion of the iris is washed with gold in the other. This is the basis for the names proposed in this report—goldeye and white-eye. There are distinguishing structural marks that are easily observed. *Alosoides* has the belly keeled in front of ventrals as well as behind, *tergisus* only behind; the dorsal fin of *alosoides* is short, with only 9 rays, and

rises above or a little behind the anal, while that of *tergisus* is longer, of about 12 rays, and rises before the anal.

The toothed herrings, or mooneyes, have been generally regarded as nearly worthless because of the large number of bones; but in comparatively recent years the practice of smoking them has developed, and the product is excellent. In the smoked condition the bones offer no special difficulty. The smoking of mooneyes has been most prevalent about Lake Pepin, where *tergisus* seems most abundant. In quite recent times, according to information received at Muscatine, Iowa, in 1926, there has been a market for fresh mooneyes; *alosoides* is apparently most common in that region.

THE TOOTHED HERRINGS (Hiodontidæ)

Gold-eyed Mooneye. *Hiodon alosoides* (Rafinesque)

"TOOTHED HERRING;" "WAP"

At Keokuk the goldeye attains a length of 44 centimeters (18 inches) and a of nearly three-fourths of a kilogram (3 pounds).

We have found virtually no published data regarding the habits, except the note of Forbes and Richardson that it is commonest in rather swift open water, is a gamey fish, and feeds mainly on terrestrial and aquatic insects, mollusks, and small minnows. At Keokuk it was found only in the river, never in the lake. It was taken both in hoop nets on the bottom near the banks and in floated trammel nets at the surface.

The stomach contents of about 29 examples were examined for us by Dr. R. A. Muttkowski. The food is almost exclusively insect. A single stomach of those examined contained fish (2 gizzard shad) but it is known that anglers, using live bait, occasionally catch a goldeye. A few small crustaceans and a trifle of plant matter also occured in the stomachs. Listed approximately in the order of their abundance, the following insects were reported: May-fly nymphs and imagos; beetles, chiefly terrestrial but including Gyrinus (whirlgig beetle) and Stenelmis; caddisworms, midges, and beach flies; Corixa (water boatmen); dragon-fly and damsel-fly larvæ; grasshoppers and crickets; stone-fly nymphs; dobson-fly larvæ or hellgrammites.

Except that fish and the largest insects are found in the larger fish, there appeared no differences in food corresponding with age as regards goldeyes varying in length from 16 centimeters (5.5 inches) to 42 centimeters (18 inches). There was also no seasonal variation in food except that terrestrial forms and adults of most aquatic insects were not available in winter. Rarely were specimens taken with empty stomachs, from which it may be inferred that the fish is actively feeding throughout the day.

The fish was taken at Keokuk from February to August. Although specimens were examined in every month from March to August (with one examination on February 29) only one fish was found that seemed sexually mature—a female taken March 29, 1915. Possibly the breeding season is in the late winter or early spring.

This fish has but little commercial value, although some are shipped in the north (Evermann and Latimer, 1910, p. 132) and from Muscatine and points near Keokuk, Iowa; it is said to have considerable value as an article of food in the basin of Lake Winnepeg (Jordan and Thompson, 1910, p. 353). The flesh is white and rich and particularly good when smoked.

The goldeye is not sufficiently abundant about Keokuk to support a large fishery. The biggest catch noted during the two seasons was 44 taken in a trammel

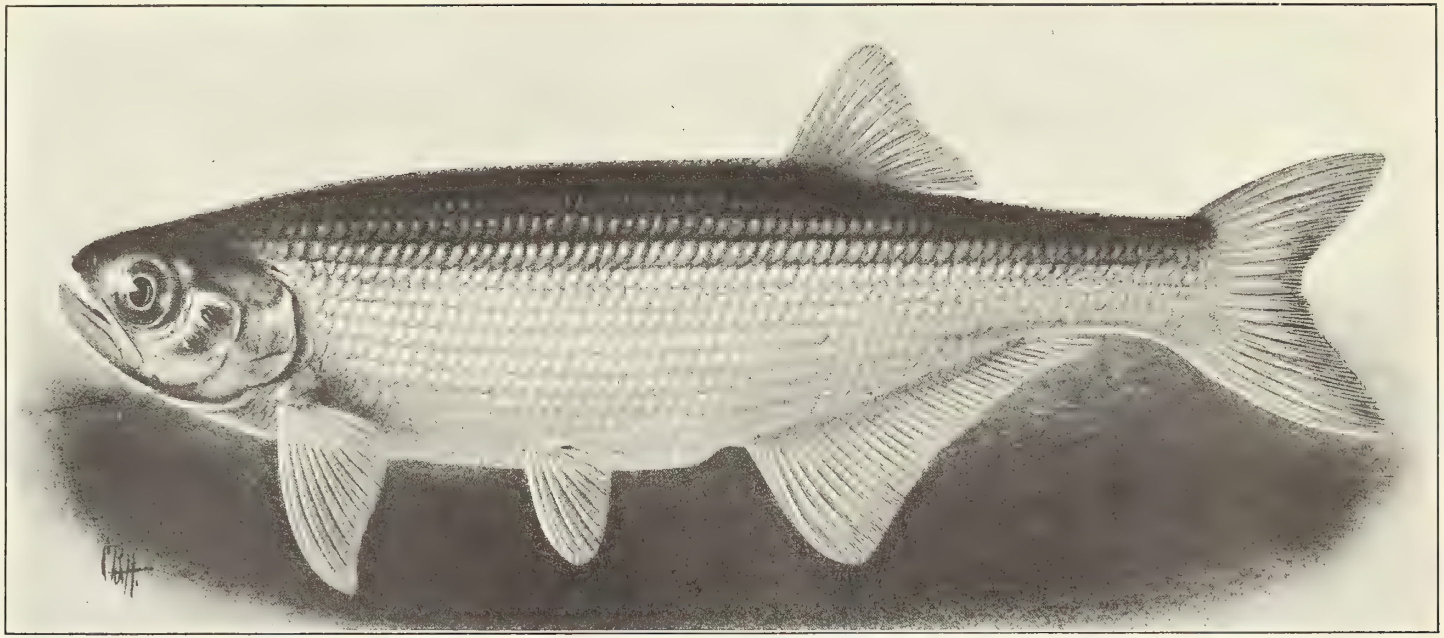

FIGURE 8.—Gold-eyed mooneye, *Hiodon alosoides*

net near the unfinished half of the power house on the evening of May 30, 1915; on June 26 of that year 28 were taken in the same locality. The fish was found about Keokuk from February to August and probably spawns in February or March. There was no indication that the dam interfered with its habits. Many years before the dam was built Forbes and Richardson wrote:

> This large and handsome silver-coated fish is now too rare in Illinois to have any special significance in our waters. Some years ago it was much more abundant than now in the Mississippi and the Ohio, as many as a thousand pounds at a time having been caught, according to Mr. Ashlock, from the former river near Alton and the latter at Cairo.

White-eyed Mooneye. *Hiodon tergisus* Le Sueur

"TOOTHED HERRING"

Although said to be very abundant in the Ohio River and in Lake Erie (Forbes and Richardson, 1908), the white-eyed mooneye was found to be much less common in

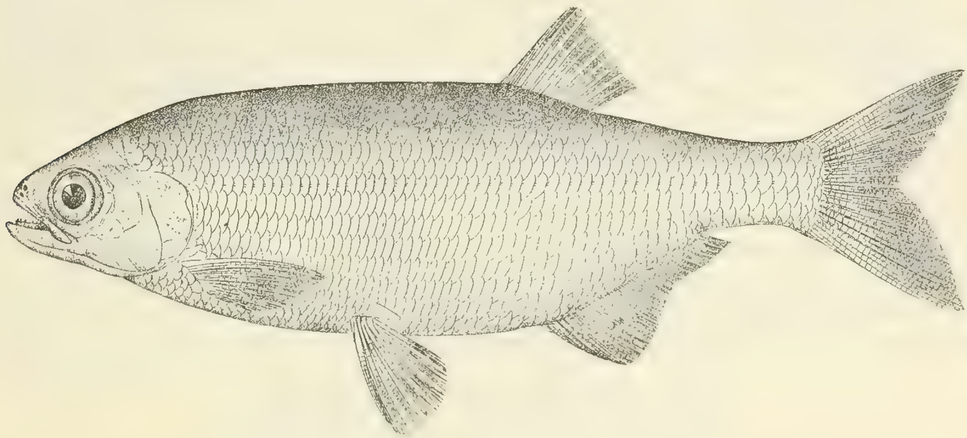

FIGURE 9.—White-eyed mooneye, *Hiodon tergisus*

the vicinity of Keokuk than the other species. The two fishes are apparently not distinguished by the fishermen of that region. It is smaller than the goldeye; the largest taken at Keokuk was 30 centimeters (12 inches) in length, but a somewhat longer specimen was taken in Lake Pepin. Fish were examined by Stringham for reproductive condition in each month from February to August (except June). Sexually mature fish with eggs flowing on pressure were taken at Keokuk on March 15. The fish varied in length from 23 to 28 centimeters (9.5 to 11 inches), and the eggs were 1.7 to 2.3 millimeters in diameter.

The contents of the stomachs of a dozen examples that were examined for us by Doctor Muttkowski comprised chiefly May-fly larvæ of various kinds (Hexagenia, Ephemera, Heptagenia, Siphlurus, Bætinæ, etc.), black-fly larvæ and pupæ (Simulium), caddis-fly larvæ (Hydropsyche), dytiscid beetles, and water boatmen (Corixa). Forbes and Richardson say that the food is chiefly insects and their larvæ, mollusks, and small minnows. It is described as a vigorous biter and gamey on the hook. It does not, however, seem to have the good qualities as a fresh food fish that the other species possess.

On several occasions the author has taken mooneye in Lake Pepin, and in all cases the species was *tergisus*, which we assume to be the more common species in that

water. About 1917 there appeared to be developing about Lake Pepin a smoking industry of significance, based chiefly upon mooneye. In 1922 and in 1927 the mooneye was not reported as a commercial fish, but this was undoubtedly an oversight, arising possibly from the fact that mooneyes were not sold from the nets but were given away or taken home to be smoked and subsequently sold. Inquiries in 1926 indicated that there had been no cessation of the practice, although little development had occurred for relative paucity of material.

In the region just below Lake Pepin some fishermen speak of a large herringlike fish locally called "cisco." Possibly this name refers to the larger mooneye, *alosoides*. Such information as we have in hand would suggest the association of *tergisus* with slacker water and *alosoides* with swift current. The respective habits and distribution of the two species offer a favorable subject for study.

SUMMARY AND CONCLUSION REGARDING MOONEYES

Mooneyes of two species are generally distributed in the upper Mississippi, one species or the other seeming to predominate in each locality. In some localities mooneyes are described by fishermen as frequenting only the swiftest current, but in other places they are found in slack water. The fish have had no significant commercial standing in the past but are now marketed in most places as smoked fish and in some localities as fresh fish. The quality of the smoked mooneyes is very high. Mooneyes appear not to have been unfavorably affected by the dam. At only one or two points on the river, either above or below the dam (as far as Canton, Mo.), was there reported in 1926 a diminution in numbers of these fish. "More than ever" was the substance of reports at Lynxville, Wis., Fairport and Keokuk, Iowa. Mooneyes may have a growing value, but they are not now so abundant, relative to other species, as to promise to take a place of great importance in the fishery.

THE GIZZARD SHADS (Dorosomidæ)

Gizzard shad. *Dorosoma cepedianum* (Le Sueur)

The gizzard shad offers an instance of a fish that has no commercial rating but nevertheless is one of the most valuable fishes in the larger rivers. Garman (1890) says that predaceous fishes confined in the sloughs depend very largely on this shad for sustenance. Forbes and Richardson (1908) speak of it as "one of the most useful in our waters because of the almost exhaustless food supply which it offers to all the game fishes of our larger streams and lowland lakes. Living itself mainly upon food derived from the muddy bottom of our very muddy rivers and lakes, it serves as a means of converting this mere waste of nature into the flesh of our most highly valued food fishes." In its earliest stages of free life, when it is remarkably different from the adult in form and habit, it competes with game fishes for the active elements of the plankton. It soon transforms itself, adopts new habits of feeding, and becomes itself the prey of young bass and other predatory fishes. Even as an adult it is still able to feed upon plankton strained from the water through its gill rakers.

The breeding season of the gizzard shad in the vicinity of Havana, Ill., begins in May, and growth is evidently rapid. Garman (1890), having collected fish near Quincy, Ill., in August, 1888, reported that "young of the year 1.5 to 2 inches long and still wearing the black shoulder mark occur in countless numbers. * * *. The bottoms and sloughs and lakes are preeminently the spawning ground of this fish."

No necessity for extensive migrations of the gizzard shad is known. It is extremely widespread in its occurrence, being found in brackish water along the Atlantic and Gulf coasts, throughout the Mississippi Valley, and in Lake Erie and Lake Michigan. It is found about Keokuk all the year, having been recorded each month from February to November (except March.) It is not remarkably abundant in the relatively strong current of the Mississippi River but occurs in great numbers in the sloughs, backwaters, and lakes. The conditions offered by the creation of the lake

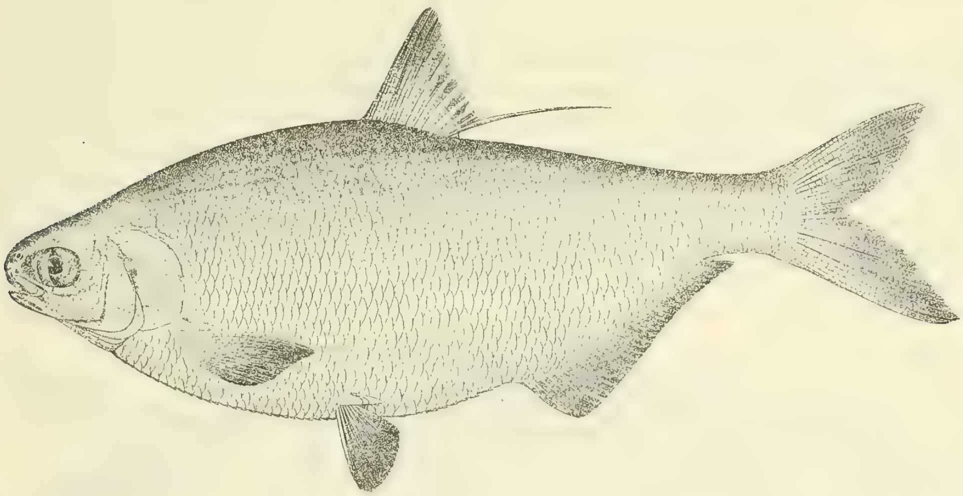

FIGURE 10.—Gizzard shad, *Dorosoma cepedianum*

may be thought to be favorable to its productivity, and we have had no evidence of any unfavorable effect arising from the presence of the dam.

THE HERRINGS AND SHADS (Clupeidæ)

River herring or "skipjack." *Pomolobus chrysochloris* Rafinesque

One of the most beautiful and lively fishes of the Mississippi Basin is the river herring, blue herring, or "golden shad," marked with its green and silvery color and golden reflections. It has a striking habit of leaping from the surface when feeding upon schools of minnows or in mere play. From this it has derived, in some places, the name of "skipjack," a designation that is applied in one locality and another to so many species of fish that it is quite indeterminate; its use should be discouraged. By a few fishermen they are very inappropriately called "mackerel." Another misleading local designation is that of "Government shad"—a name applied apparently in the belief that the river herring are the result of former Government plantings of Atlantic shad.

The river herring has no importance as a food fish, being very bony and lacking good flavor. Its liveliness and vigor, however, make it one of the gamiest fishes in the river, so that it affords real sport to the angler who fishes with live bait in swift water, as about the ends of wing dams. An insight into its habits was had by the author and an aide as they fished for herring in the swift waters just below the chute alongside the lock. The fish played about the boat in great numbers, darting through the water, leaping from the surface, taking the line and making the reels spin busily, only to release themselves when a strain was put upon the line. After a time it was

found that the fish were taking the spindle-shaped lead in the mouth rather then the baited hook. The very swiftness of the fish prevented an earlier discovery of the trouble. With the leads removed from the lines and the bait kept close at the surface the fish were caught in fair numbers.[12]

Notwithstanding its poor qualities as a food fish, the river herring represents a very distinct economic asset. The niggerhead fresh-water mussel has been regarded as the most valuable of all the pearly mussels of the Mississippi Basin because of its abundance in all the larger waters of strong current and because it yields a shell of the best quality for buttons. Until quite recently, at least, most of the highest-grade pearl buttons of domestic manufacture have been produced from niggerhead shells, and these owe their existence to the river herring. The reproduction of the niggerhead mussel, so far as all evidence goes, is accomplished only through the parasitism of its young (glochidia) upon river herring; there can be no beds of niggerhead mussels except in waters frequented by river herring. It is, then, economically desirable to maintain the stock of river herring in all waters to which it is adapted and in which the bottoms are suitable for the mussel. As matter of fact, however, it

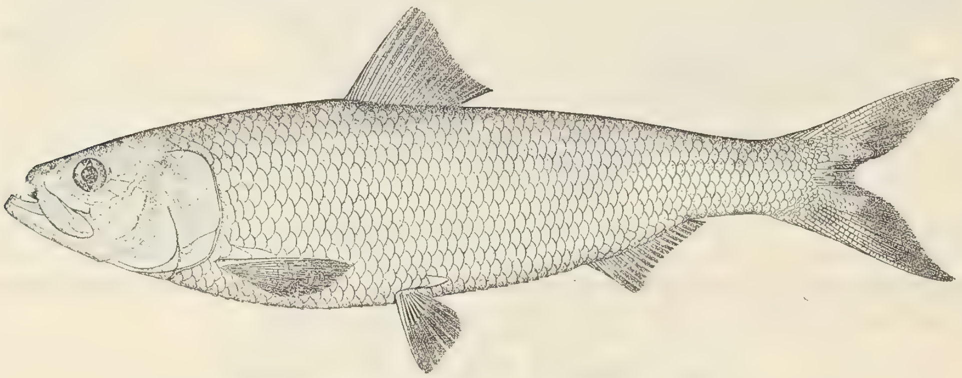

FIGURE 11.—River herring of the Mississippi River, *Pomolobus chrysochloris*

was found in 1926, by inquiry of manufacturers and shellers and by examination of shell heaps on the river bank, that the niggerhead is a vanishing species in the upper river, its place being taken to a considerable extent by other kinds of mussels.

There have been no published observations concerning the breeding of the river herring. Our records throw some light on the question, although we did not succeed in determining the place or the precise time of spawning in the vicinity of Keokuk.

Fish full of roe were taken by the author on April 29, 1914, at the very beginning of the "run" of river herring. Eggs and milt were exuded when pressure was applied. It was supposed that the spawning season was almost at hand, and in the course of the next few weeks attempts were made to obtain clearly spawning fish, but without success. On May 23 of the same year females full of roe were taken and one that was possibly spent. Stringham in 1915 examined, for reproductive condition, 191 fish from April 19 to September 22. Testes and roe, developed nearly or quite the full length of the abdominal cavity, were found April 29 and 30 and on various dates thereafter. Eggs measuring 0.8 millimeter were found as early as May 24, and eggs of 1.1 millimeters on June 5. Milt issuing on pressure was first noted June 23, and on

[12] Stringham examined the stomach contents of about 150 river herring. Approximately one-third were empty; a little more than one-third contained fish, chiefly minnows, with some mooneyes, gizzard shad, and other fish not determinable; and less than one-third contained insects and larvæ, principally May flies, with some caddis flies and others.

the same date was recorded "possibly a spent female." For July 1 and 2 occur the records "eggs flowed on pressure." After the latter date no fish were found with well-developed reproductive organs.

In 1916, 19 fish in all were examined on 12 dates between May 8 and August 30. The following records are of interest: May 23, "eggs flowed from dead fish"; June 3, "milt flowed slightly on pressure"; June 17, "eggs 0.8 millimeter"; July 14, "possibly spent female." At practically all times fish of considerable size were found with reproductive organs in undeveloped condition.

Many attempts made during several years to find a particular place and time where and when river herring were clearly spawning met with no success, although various methods of capture were tried. The problem proved unexpectedly baffling. Our data suggest only that the spawning season is prolonged, possibly beginning early in May; that the fish do not spawn in large aggregations; that during the spawning operations they are not readily captured by ordinary methods of fishery; and that spawning is ended soon after the first of July.

The river herring is classed by local fishermen as an "early-run" fish—that is, one of those that appear in numbers at Keokuk on the Mississippi and at Ottumwa on the Des Moines at the beginning of the fishing season, or about April 15 to 30. Other fish of the same season are hickory shad, sturgeon, bass, pike, and pickerel, followed a little later by channel cat and then buffalo and carp. In 1914 they appeared at Keokuk about April 22 and were extremely abundant below the dam on April 29. The first herring recorded by Stringham in 1915 was on April 19, and the first record of 1916 was for May 8, although they may have been present earlier. The fish were not so abundant in 1915 as in 1914 and were still less numerous below the dam in 1916. Whether this was due to actual diminution in the abundance of fish in the river, or whether the fish, having encountered the obstruction for one or two years, had been diverted to other waters can not be determined. In 1926 herring were reported to be abundant below the dam, some alleging that they were more abundant than before the dam.

The aggregation of herring below the dam in 1914 was so striking that we may refer to the observations recorded by the author in another place (Coker, 1914, p. 25) and quoted in part on page 94 of the companion report (Coker, 1929). No herring had been in evidence when the writer was at Keokuk on April 15, while the water was still cool.

A local informant, Mr. Joe MacAdams, was requested to write me of the first appearance of the herring. After a card from him, I visited Keokuk again April 29. He stated that the herring first appeared April 20, and that they became enormously abundant within a few days; on the 27th according to several informants, during a warm day, one could at any moment see hundreds of them breaking the water in every part of the river below the plant.

Then followed the personal observation of a remarkable assemblage of herring, which is described in the paragraphs quoted on page 94 of the companion report. (Coker, 1929.) The further observations not previously quoted are relevant.

It was observed that the roe of the herring was large, and it was thought that they would ripen within a few weeks. A visit was made by Superintendent Canfield May 29, and a number of herring were examined, but they were found to be not quite ready for spawning. A later visit was made by Mr. W. B. Gorham, June 11 and 12, when it was found that the herring had disappeared. This disappearance had not been noted by the local fisherman for the reason that there were present in large numbers the Ohio shad, *Alosa ohiensis*, which is not generally, if ever, distinguished by fishermen from the herring. There was no clew, therefore, as to what had become of the herring.

(Later observations, in August, indicated that the disappearance was only temporary.)

So far as is now known, the herring is to be found at Keokuk only from April to September. In 1915 they were captured principally between June 13 and July 11, a condition quite different from that of 1914.

As to conditions above the dam, seining was inaugurated at Montrose, Iowa, midway of the lake, in 1916, and herring were reported to be taken frequently. Two examples were examined by Stringham on July 14. The fishermen, who were visited from time to time, reported the more or less regular capture of herring in small quantities during August and up to September 15.

In Lake Pepin in 1913 the catches of herring by the bureau's seining crew were made from July 29 to the end of operation on the lake—September 11. In 1914 a single specimen was caught on May 12 and a few about the middle of June, after which they were taken more plentifully, particularly in the middle and latter part of July. (For dates, see Coker, 1914, p. 27.) The fish taken in Lake Pepin were noticeably smaller than those taken at Keokuk, suggesting that they were not escapements through the lock. Subsequently it was found that fish 4 to 6 inches in length could be taken in Lake Pepin, thus leading to the conclusion that breeding occurs in the upper river.

Kirsch (1892) collected six small examples of *Clupea chrysochloris*, Rafinesque, in the Wolf River near the mouth of Willis Creek, Clinton County, Ky. Garman (1890, p. 142) records the capture of small herring 2.62 inches in length in the vicinity of Quincy, 30 miles below the dam; but there is the possibility that these were young Ohio shad, for he so called them, although applying the scientific name of the river herring. Such records suggest that breeding occurs in regions south of Keokuk.

The river herring belongs to a group of fishes of very anadromous habit (including shad and alewives), and we were therefore uncertain as to whether or not extensive migrations were necessary for its propagation and distribution. Did it spawn in the upper waters and migrate southward? Could the stock of river herring be maintained in both the upper and the lower sections of the river while there was an effective barrier midway of the stream? The question of the maintenance of the fish in the portions of the river above and below the dam, respectively, ought, it seemed in 1926, 13 years after construction of the dam, to be answerable by further observations in Lake Pepin and at Keokuk and below.

There is no question that during the three years immediately following the construction of the dam there was a decided decline in numbers of fish appearing at Keokuk and in the numbers taken in Lake Pepin. The records of collections in Lake Pepin by our seining crew for the years 1914, 1915, and 1916 were as follows: 4,189 in 1914, 2,288 in 1915, and 42 in 1916. These observations led us to suppose that these fish were rapidly decreasing in numbers in the upper part of the river.

In August, 1926, the author witnessed several seine hauls in Lake Pepin, in each of which one or two river herring were taken. They were evidently not rare, relative to other fish, for, exclusive of gars and pickerel, not a tubful of fish was taken in any haul. Furthermore, it was the testimony of several commercial fishermen that "the herring were coming back," although all say that present abundance can not compare with that of a dozen or more years ago. It is an undoubted fact that in former times herring were often a nuisance to anglers fishing for pike in swift waters at the ends of wing dams, whereas in recent years a herring rarely takes the hook.

Herring are still taken by the seining crew at the Fairport (Iowa) station and are reported by commercial fishermen at various points on the river. At Keokuk and below at Warsaw, Ill., and Canton, Mo., herring were said to be as plentiful (in 1926) as ever and even more plentiful than before the dam was built. Many of the fish seen near the last-mentioned places may, of course, be headed for the Des Moines River, which enters the Mississippi only a little below the dam. The swift current of the Des Moines seems well adapted for the river herring, which is known to frequent it.

CONCLUSIONS REGARDING THE RIVER HERRING

These facts seem now reasonably clear: Just after the dam was placed, river herring, at the approach of the spawning time, gathered in enormous numbers just below the obstruction. These assemblages became less conspicuous in succeeding seasons (for 2 or 3 years) but are still observable after 13 years. During the first few years after the construction of the dam the herring in the upper part of the river rapidly declined in abundance until a relatively low point was reached. The stock, which has been in a depleted condition, has been maintained up to the date of most recent information (1926), when there was reported to be noticeable evidence of partial recovery. Even while the decline was most rapid, there was evidence of breeding in the upper part of the river in the numerous small herring taken in the bureau's seining operations in Lake Pepin. Breeding must also take place below Keokuk, since the herring appear at Keokuk in as great or greater numbers than were known before the dam was built 13 years previously. These facts would all comport with the supposition that the herring are extensively migratory but do not necessarily go to extreme northern or extreme southern waters, and that the breeding places from which the upper river was formerly chiefly stocked are no longer accessible to a great number of herring. The evidence points to the fact that one effect of the dam was to bring about a substantial diminution in the herring population of the upper river, and that this may account in part for the decline of the niggerhead mussel in the upper river.

Ohio shad. *Alosa ohiensis* Evermann

Almost nothing has been known about the indigenous shad of the Mississippi Basin. Although recognized by many fishermen, it was unknown to science until 1902, when it was described by Evermann (1902). It is, according to him, much longer and slenderer than either the Alabama or the Atlantic shad, females having the depth scarcely more than one-fourth the length, and the males being still more slender. Although a true shad, it is more herringlike in form; its specific distinctness, as compared with the Alabama shad, has, however, been questioned by Regan (1916). While we found the shad very common at Keokuk for a brief season, we know of no previously published record of its occurrence in the Mississippi. Our specimens and photographs were destroyed by fire in 1917. The illustration herewith is from a photograph of a preserved specimen; it will serve to enable one to distinguish the shad from the river herring. Note especially the form of the mouth and the shape of the cheek.

The Ohio shad in the Mississippi has no present economic value but must be treated as a potential asset, for Evermann (1902, p. 283) says that those who are familiar with the delicious Atlantic shad and who know how to prepare it find the Ohio shad not at all inferior; and Stringham, after many trials, concurred in that

opinion. It is comparatively small for a shad, not attaining a weight greater than about 2¾ pounds. A few have been handled commercially on the Ohio River.

Shad were marketed from that stream and its tributaries to the extent of 6,950 pounds in 1899 (Townsend, 1902) and 8,750 pounds in 1903 (U. S. Bureau of Fisheries, 1904). Since the average price in the latter year was 10 cents a pound to fishermen, it is evident that the fish were purchased for food rather than for bait. It is an interesting commentary upon the state of knowledge of our aquatic recources that while Federal and State governments in the eighth and ninth decades of the last century were making serious efforts to introduce the Atlantic shad into the Missisippi Basin the native shad remained generally unutilized and unknown. Evermann reported its use only as bait for catfish. Should it be utilized as a food fish, it would be necessary carefully to distinguish it from the river herring, a distinction that need offer no serious difficulty.

It was reported to Evermann that the fish was first taken about Louisville, Ky., in 1896, and that a great increase in the catch came in 1897 with the adoption of surface-fishing seines in lieu of the bottom-fishing seines previously used. Lightly leaded seines fishing in the upper few feet of water took Ohio shad along with spoonbill, the runs of the two species occurring at the same time, principally the latter part of May.

There were many Ohio shad at Keokuk in 1915, enough, it is believed, to support a substantial fishery. No effort was made to secure them, but Stringham examined more than a hundred that chanced to be taken and saw many more. In 1916 there were comparatively few, only 35 being handled by him. In the experimental net used on the top of the lock gate, the shad was taken more abundantly than any other fish except the river quillback and the spotted catfish.

All shad seen at Keokuk were taken during a short season extending from early in May to the middle or latter part of July—May 3 to July 12, 1915, and May 16 to June 25, 1916. Not one was seen at another season. All fish examined during these seasons were either sexually ripe or approaching that condition. It is evident that their presence at Keokuk coincides with a period of spawning migration. Whether they come from salt water in the Gulf, and how far north they would go—these are questions for answers to which there are no data.[13]

The fact that there are no records of the capture of this fish above the dam has no significance, because there were no records for the river at all before the dam was constructed. Locally the fish has been confused with other species, and such shad as were identified were assumed to be Atlantic shad introduced by the Federal Government. This applies to three specimens, numbered 21,345 among the collections of the National Museum, taken May 3, 1878, in the Ohio River. The experiment with the trammel net on the lock gate (Coker, 1929, p. 100), in which 45 Ohio shad were taken from the lower side, and only one from the upper, suggests strongly that the fish were endeavoring to pass the dam. If the fish occurs in West Virginia, as stated by Townsend (1902, p. 664), it is there at least 125 miles farther from the Gulf than at Keokuk. The Ohio shad came abundantly to the dam during spawning migration, and it is extremely improbable that the dam had chanced to be constructed precisely at the upper limit of the path of migration. We must assume, then, that the dam checks the upward course of the fish.

[13] At Lynxville, Wis., Mr. Kaya described a second kind of herring in such terms as to suggest the Ohio shad; the fish had formerly been taken in seines, not with hook and line.

Figure 12.—Ohio shad, *Alosa ohiensis*. (From a preserved specimen)

Stringham examined the stomachs of 163 examples (118 in 1915 and 45 in 1916) at all dates of collection. Most of them were empty and none had more than an insignificant amount of food. The records for those containing any sort of materials follow:

TABLE 2

Date	Locality	Stomach contents
1915		
May 1-7	Canton, Mo.	4 examples containing traces of food, kind not determined.
May 15	Keokuk, Iowa	1 example, matter in alimentary canal not determined.
May 27	do	Do.
May 29	do	3 examples contained particles of matter, probably fragments of vegetation.
May 31	do	Several out of 36 sepcimens contained fragments, probably vegetation and insects. 1 contained the remains of a lady beetle; 1 a little piece of wood and unrecognizable insect débris; 1 plant remains and unrecognizable débris.
June 5	do	2 contained fragments of food.
June 6 [1]	do	1 contained minute food remains.
1916		
May 23		2 contained remains in duodenum, including insect remains.
June 11		1 contained Hexagenia May-fly nymph in stomach.
June 14		1 contained particles of insect remains.
June 21		1 contained particles of Anisopteran dragon-fly nymph and plant remains in duodenum.
June 24		1 contained particles of plant remains in stomach.
Do. [2]		1 contained particles of plant remains in duodenum.

[1] Examination continued to July 12, with all stomachs found empty. [2] No examinations after June 25.

The records are significant. Of 163 examined, 105 were empty, if not more (record not complete for 36 specimens of May 31); 5, and a few of May 31, contained small quantities of food—recognizable insect remains; 6 had particles of plant materials; 1 had a piece of wood and unrecognizable débris; and one had plant hairs and unrecognizable débris. It may be inferred that the fish are not feeding when at Keokuk. It is known that fish, when under conditions where feeding is not a normal habit, do not altogether lose the instinct of snapping at objects in the water, and so may sometimes take into the alimentary canal living or dead material. The food records suggest a strongly anadromous habit for the Ohio shad. Clearly the life history and migrations of the fish offer a nice subject for study.

CONCLUSIONS

The Ohio shad, a fish not utilized at present but of great intrinsic value as a food, is strongly anadromous in habit. It visits Keokuk in May, June, and early July while in upstream migration to spawning grounds, but is stopped by the dam, save for a very few that may pass through the lock. The extent to which they formerly ascended beyond Keokuk is not known and may never be known. Apparently, it is not normally feeding when at Keokuk.

American eel. *Anguilla rostrata* Le Sueur

The eel, of course, is unique among our fresh-water fishes in spawning only in the sea. While not an anadromous fish, but the reverse, a catadromous species, there can be no argument as to the possibility of its continued existence above an impassable barrier. Our only question would be, first, whether the barrier is impassable for eels, and, second, whether the exclusion of the eel from the upper part of the basin is of any consequence.

As to the first question, the eel is so powerful and so rapid in movement, such an inveterate prowler, and so able to pass over places that are virtually closed to other

fish, that we can not readily dismiss the possibility that eels find their way beyond the dam, both in upward and downward migration. However, when we consider the physical condition of the dam at Keokuk (Coker, 1929) the very nicety and completeness of its construction, it becomes evident that there is no possible passageway upward except the lock, and that few can pass through this. Not one eel was taken in the trammel net operated on the lock gate, nor was one reported from the catches on the gate itself.

In the Mississippi River and its tributaries above the dam the eels that were there before the dam was constructed and the few that may pass through the lock may live and come to maturity, but without a better passageway than now exists there can not be an important eel population in that region. If, however, we examine the statistics of commercial fisheries we find that the eel has never been of commercial importance in the upper waters of the Mississippi. (Table 3.)

TABLE 3.—*Catch of eels, in pounds, in States bordering the Mississippi River in 1899, 1908, and 1922* [1]

State	1899	1908	1922	State	1899	1908	1922
Minnesota	900	800	540	Arkansas	3,702	----------	0
Wisconsin	1,745	1,600	313	Kentucky	3,900	300	0
Iowa	10,943	5,400	0	Tennessee	14,180	3,100	578
Illinois	29,263	31,000	10,500	Mississippi	3,930	0	0
Missouri	6,456	17,000	3,000	Louisiana	1,670	0	0

[1] Data for 1899 from Townsend (1902); for 1908 from U. S. Bureau of the Census (1911); for 1922 from Sette (1925).

It is evident from these figures that the yield of eels in past years has been greatest neither in the extreme lower portion of the Mississippi River nor in the upper portion but in the middle section where the river flows between Illinois and Iowa, Missouri, and Tennessee. The catches in Minnesota and Wisconsin have never been significant. We are only surprised that 10 and even 15 years after the construction of the dam eels should be taken at all in the extreme Northern States. However, it is understood that eels may remain in fresh water for as much as 18 years. It must be understood that there is no special eel fishery with appropriate apparatus, and, therefore, that even a small catch suggests that eels are not uncommon.

In 1926 the author inquired regarding eels of fishermen at various points on the river from Lake City, Minn., to Canton, Mo. At all places it was reported that eels are still captured occasionally—two or three a year, perhaps. Only one fisherman above Keokuk spoke of seeing small eels in recent years. Eels taken in the lake and above are usually 3 pounds or more in weight, up to 7 pounds.

On the other hand, below the dam, at Keokuk, small eels are reported as taken commonly. Market reports were that many were too small to buy. The smallest seen by the author was at Canton, Mo.; it weighed 9 ounces in the rough. Luther McAdams, a careful observer, said that in the fall of 1925 he observed and caught large numbers of eels about the size of a lead pencil. They were on the apron of the dam below a closed spillway and were trying to follow up a small stream that came from a leak in the gate above. They would work up the face of the spillway 3 or 4 feet and fall back again. He gathered about a half bushel of them. William Stanton, a fish dealer, said that a diver had reported to him the presence of enormous numbers of small eels in the lower part of the drift chamber below a turbine. If such aggregation

of eels can be found each year, it would be desirable to collect the small eels and transfer them to the waters above, so that they might continue in migration.

If the dam at Keokuk is an effective barrier, as we suppose, eels should in time cease to be found in Minnesota and Wisconsin and in Iowa, except in the Des Moines and Missouri River systems, and in Illinois in a little more than one-third of the Mississippi bordering Illinois and the tributaries of that portion.

Unfortunately, it appears that future statistics of the eel fishery will be of little significance with reference to the effect of the dam, for the reason that the eel is evidently rapidly and steadily disappearing from the whole basin. This is a fact that arrests our attention, particularly because it can not be attributed to any obvious cause. The fishery for eels has been so small that we can hardly suppose it to have had a material effect. The steady decline of the eel fishery in the Mississippi and tributaries is indicated in the following table:

TABLE 4.—*Eels taken in the fisheries of the Mississippi River and tributaries for various years*

Year	Pounds [1]	Percentage of decrease	Period since last survey, years	Year	Pounds [1]	Percentage of decrease	Period since last survey, years
1894	133,223			1908	61,000	17.8	5
1899	93,905	29.5	5	1922	16,060	73.7	14
1903	74,210	29.7	4				

[1] Figures from Sette (1925, p. 211).

The decline in catch is so regular and has extended so far that one might suppose that the next two or three decades would witness the complete disappearance of eels from the basin.

SUMMARY

The eel is stopped in upward migration by the dam at Keokuk and must virtually disappear from the river and its tributaries above the dam. However, the eel has never been of commercial importance in the upper part of the basin. Furthermore, for at least 30 years the eel has been steadily disappearing from the whole basin, so that without a change of trend it will soon cease to count as a natural resource of the region.[14] There is suggested the possibility of rescuing young eels collected at the base of the dam and passing them over in baskets.

THE CATFISHES (Siluridæ)

The catfishes rank next to the buffalo fishes and carp in commercial importance. In 1922 the product from the Mississippi Basin alone (Atchafalaya River included) was valued at nearly $750,000. Of about half a dozen species found at and near Keokuk three were present in substantial numbers. One or more of the bullheads (Ameiurus) are probably abundant in quiet waters but are uncommon in the river. As with the buffalo fishes, all kinds of catfishes are lumped together in statistical reports, so that it is impossible to apply the returns in the consideration of individual species. We may first see, however, what has been the general trend of the fishery during the past 30 years, as shown by the figures assembled by Sette (1925, p. 209),

[14] For possible future reference it may be recorded that during the four months from May to August, inclusive, 1916, there were handled by the markets at Burlington about 125 eels and by the markets at Fort Madison (principally in June) about 700 eels. Only one or two dozen were handled by dealers at Warsaw, Ill., and Alexandria, Mo., during the three summer months of 1916.

showing the yield of catfish from commercial fisheries of the Misisssippi River and tributaries, not including the Atchafalaya River.

	Pounds
1894	9, 689, 034
1898	7, 648, 179
1903	5, 191, 850
1908	8, 073, 000
1922	6, 263, 025

The fishery has evidently been fairly uniform; the fluctuations during a long period as shown by these figures, are not striking, except perhaps for the low point reached in 1903.

Fulton cat. *Ictalurus furcatus* (Le Sueur)

BLUE CAT; CHUCKLEHEAD CAT

Locally known by the distinctive name of Fulton cat, this species is the largest of the Mississippi River catfishes.[15] In fact, among all the food fishes it is rivaled in

FIGURE 13.—Fulton catfish, *Ictalurus furcatus*

size only by the paddlefish and lake sturgeon, and large examples of these are not now common. It sustains an important fishery in the south (Evermann, 1899, p. 305), where it is most abundant, but many were taken in the vicinity of Keokuk during 1915 and 1916, the latter year being reported by fishermen as the best they could remember for Fulton cats. According to Forbes and Richardson (1908), it frequents the deeper waters of the river channels, coming out into the shallow sloughs and backwaters in spring. Some fishermen say that it prefers rocky bottoms. On June 1, 1915, in the slack water of a creek near Keokuk, three large Fulton catfish were taken in nets along with the buffalo fishes subsequently to be mentioned, the largest having a total length of 30 inches (76 centimeters).

This catfish is reported to breed in Louisiana. (Evermann, 1899, p. 294.) The observations made by Stringham indicate that it breeds near Keokuk, probably about June. On June 10, 1915, there were seen at Canton, Mo., 20 miles below Keokuk, three Fulton catfish with eggs nearly or quite ripe and another with small eggs, possibly

[15] Evermann (1902) says: "I have been told that one was taken weighing 185 pounds, and another 250 pounds." Forbes and Richardson (1908) say: "It grows to a great size, specimens weighing as much as 150 pounds being occasionally caught, although the average size of the larger ones is only 15 to 20 pounds." Meek (1890), speaking of *Ameiurus nigricans*, a name formerly but erroneously applied to large examples of the Fulton cat, spoke of it as the largest catfish found in Iowa and said that examples weighing 200 pounds were reported to have been taken in past years, but that, about 1890, it seldom attained a weight of 60 pounds. He added that in Iowa the fish was known only from the Mississippi River.

a spent fish. In 1916 eggs about mature were received from Luther McAdams, who had obtained them from six large Fulton catfish purchased June 17 near Alexandria, Mo. The eggs attain a diameter of 2.5 millimeters. The species is not known to breed north of Keokuk, nor is there even a definite record of its occurrence north of that point; [16] but the absence of records signifies little, since the fishes of the Mississippi River have been little studied. Confusion arises from the fact that the spotted cat in a certain phase is frequently called Fulton or blue Fulton. At Keokuk, however, commercial fishermen and dealers usually distinguish the species correctly.

From the best information obtainable, Fulton catfish were always rare in the vicinity of Muscatine and Fairport, Iowa, but, before the construction of the dam they were not uncommon at Keithsburg, Ill., and were seasonally abundant in the old rapids just above Keokuk. Mr. Kaya, at Lynxville, Wis., stated that he had seen rare examples in that vicinity. Evidently the rapids at Keokuk marked the normal upper limit of range in the Mississippi River for most of the fish of this species.

In 1916, the banner year for Fulton catfish at Keokuk, the unusual abundance was quite local, not extending even to Canton, 20 miles down the river. Examples were seen by Stringham each month from May to September, the earliest record being May 2, 1915, and the latest September 15, 1916; but Trumer Jackson, of Warsaw, Ill., had one on April 23, 1915, and again two in October of the same year. Diligent inquiry among fishermen failed to elicit a single report of the Fulton cat having ever been taken locally in winter, and, as the fish is highly esteemed it would almost certainly be captured sometimes, and remembered, if it were present.

According to information received in 1926, Fulton catfish are still commonly taken in the river just below Keokuk, especially in the latter part of May and in June and July. Only rarely is one ever taken northward of the dam near Montrose or above. It likes rocky bottoms, so that the rapids was a favorite haunt before the dam intercepted the passage way from the south to the rapids. The author obtained a freshly caught specimen at Warsaw, Ill., on August 24, 1926.

The principal apparatus of capture at Keokuk is the set line, operated anywhere in the river. From Keokuk, southward, they were taken by "jugging," short lines being attached to floats or jugs, which are watched from small boats as they float down the river. In 1926 that practice was said to have been discontinued except as a mode of sport fishing. They are now taken in floating trammel nets, but occasionally a Fulton is found in a fyke net.

The indications, then, are that Keokuk is near but not quite at the northern limit of the summer range of the Fulton cat, and that, if not checked by the dam, they might still proceed a little farther north. It is thought that in the vicinity of Keokuk the fish breed in June.

Spotted cat. *Ictalurus punctatus* (Rafinesque)

CHANNEL CAT; FIDDLER

The spotted cat, the most widely distributed and most generally esteemed of all catfishes, is commonly known in the Mississippi when small as "fiddler," and when large as channel cat. Some are also called, unfortunately, blue Fultons, the form of the blue Fulton being said to be intermediate between fiddlers and channel cats.

This catfish occurs throughout the Mississippi Valley and the Gulf and Great Lakes regions. Its range extends from Florida and northern Mexico to Ontario and

[16] Meek (1890, p. 70) refers to it as not common in Iowa, and found only in the larger rivers.

Winnipeg; it has been successfully acclimatized in the Potomac River. Relatively small, finely flavored, attractive in appearance, trim and gamey, it is esteemed by anglers as well as by commercial fishermen. It rarely exceeds 5 pounds in weight, though it may attain a weight of 10 pounds or even, according to Forbes and Richardson, 15 or 20 pounds. It is the species of catfish principally taken at Keokuk. Although individually smaller than either the Fulton cat or the goujon, it is so much more numerous that it constitutes the bulk of the total catch of catfish. It is the predominant catfish in all sections of the river from Canton, Mo., to Lake City, Minn.

There is no reason to suppose that the breeding of spotted cat is geographically localized. The fish was bred at Washington, D. C. (U. S. Commissioner of Fisheries, 1894, p. xxxix; Worth, 1895, p. 96; U. S. Commissioner of Fisheries, 1912, p. 17), and in ponds at the Fairport (Iowa) station (Shira, 1917 and 1917b). There are also reports of breeding in Kansas (Wampler, 1895, p. 10), but in this case the identification of the species was not confirmed. Although there are general statements in the literature regarding the breeding of spotted cats, we know of no recorded obser-

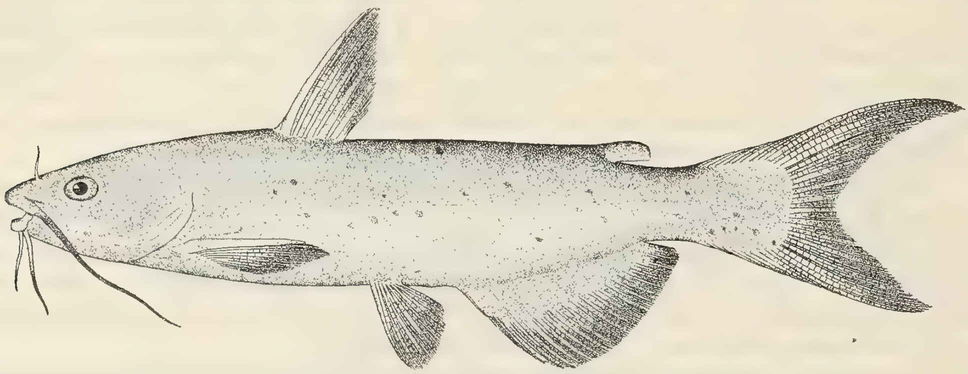

FIGURE 14.—Spotted catfish, *Ictalurus punctatus*

vations of breeding in nature. Examples containing large eggs have been collected at Fairport, and young were taken near Homer, Minn., in 1916, by Superintendent D. C. Booth of the United States Bureau of Fisheries. The observations at Keokuk that bear upon the breeding season were as follows: One fish with eggs in an advanced condition taken on set line near the power house, July 2, 1915; three with eggs in advanced condition seen in a market at Fort Madison, Iowa, June 2, 1916; two that seemed to have spawned recently seen in the Warsaw market, July 26, 1916; six examples in similar condition seen at Keokuk, August 1, 1916. Small fish, probably yearlings, were taken near Keokuk on several occasions.

The author in 1914 initiated experiments at Fairport in the pond culture of this species. Prompted by a chance observation of the nest of a catfish of another species found in an old pitcher in a lake in Michigan, he had 66 brood fish placed in a small pond having pieces of tile drain and nail kegs half buried in its banks below the water level. The water was roily much of the time and no signs of the fish were seen, but when the pond was drained in the fall nine young were obtained. The experiment was repeated the following year with almost identical result, seven young catfish 4 to 8 inches long being found in addition to the brood stock. It was evident that breeding had occurred each year, but the young had largely disappeared, probably devoured

by the predacious older fish. In the following year (the experiment being then under the supervision of A. F. Shira and H. L. Canfield), 34 fish, including some of the original brood stock, were placed in a larger pond similarly equipped with nesting places. Again no signs of spawning could be seen from the banks, but early in July the pond was slowly drained, and on July 6, when the greater part of the bottom was exposed, Superintendent Canfield saw a catfish of 3 or 4 pounds weight with a school of fry near by. Further examination showed that there were still fry in one of the kegs, and in another a glutinous mass of eggs adhering to the lower side of the keg, the individual eggs averaging 3.53 millimeters (about 0.14 inch) in diameter. It was found possible to hatch the eggs and to rear the young in ponds. After that time the experiment was repeated many times and with general success, except that the number of nests occupied and the number of young obtained was disproportionately small relative to the number of available breeders. The channel catfish, however, is not supposed to be primarily adapted to life in small ponds. Nevertheless, the experiments established the practicability of the propagation of spotted catfish under artificial conditions.

In 1926 the testimony was universal that channel catfish had greatly increased in abundance in the river above the dam, from Keokuk to Oquakwa at least. The evidence of the statistical surveys, referring to all species of catfish, is to the same effect.

The channel catfish, as its popular name implies, likes swiftly flowing water but is not restricted to regions of strong current. It is very common, for example, in Lake Pepin. It must have migratory habits at one or another stage of its life, for, in the words of Forbes and Richardson (1908), "the young of this species have * * * a much wider range than the adults and are frequently abundant in headwater streams and creeks, in which full-grown individuals are never taken."

Spotted catfish are taken in all parts of the river about Keokuk and by nearly or quite every kind of tackle used. Examples were seen in each month except November and December, and it is believed that they are present all the year. While the fish are evidently nomadic, there was found no evidence of migratory movements such as would be significantly hampered by the dam.

Niggerlip. *Ictalurus anguilla* Evermann and Kendall

PONEHEAD

The niggerlip catfish, or ponehead, well known to fishermen throughout the greater part of the course of the river, has proven somewhat elusive to the student of fishes. It is so evidently different in appearance from any other catfish as to be readily recognizable to the uninitiated. On the other hand, it conforms in so many diagnostic characters to the spotted catfish as to be puzzling to the scientific analyst. Externally viewed, it differs from the latter fish chiefly in proportions, in color, and in appearance of the integument—characters that are manifestly difficult of strict definition; as yet there are no adequate expressions of the variable proportions of either *punctatus* or *anguilla*, and both species undoubtedly manifest different proportions and peculiarities of appearance at different ages and perhaps at different seasons.

Stringham encountered no examples of the niggerlip at Keokuk, unless they were the fish locally and inappropriately called "bullheads," which were thought to be a phase of the variable channel catfish. Forbes and Richardson (1908) associate the

name "niggerlip" at Grafton and Alton with the species *anguilla*. In 1926 the author obtained specimens of niggerlip at Dallas City, Ill., taken in the lake, and at Canton, Mo., below the dam. A positive identification did not seem possible on the basis of the published descriptions and the limited amount of material available, but the fish were provisionally assigned to the species *Ictalurus anguilla* Evermann and Kendall, known in Louisiana as "eel cat" or "willow cat." A difficulty in identification arises from the fact that, with both *punctatus* and *anguilla*, the proportions vary markedly with age. Several of the probably diagnostic ratios of dimensions of niggerlip catfish 60 centimeters in length were found to agree closely with corresponding ratios for spotted catfish 30 centimeters long, although distinctly different from those of spotted catfish 56 centimeters in length. A careful study of channel catfish and niggerlip catfish at all sizes not only would serve to clear up doubts as to the identity of the latter fish but would also make a valuable contribution to the systematics of American catfishes. In almost any locality fishermen distinguish three phases of the

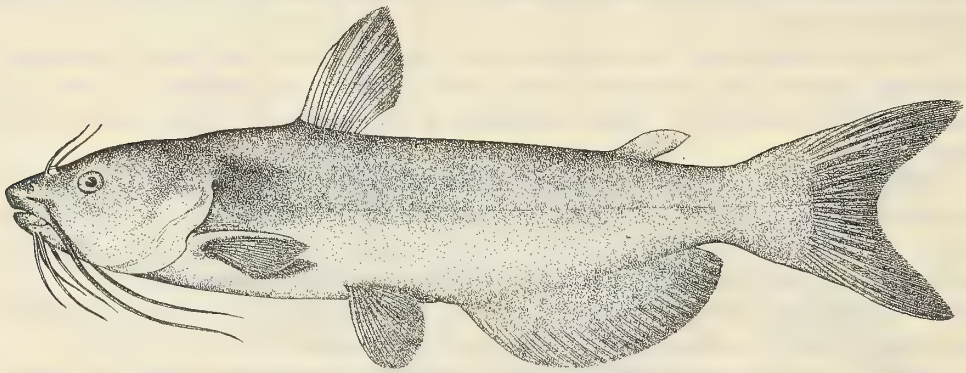

FIGURE 15.—Eel cat, willow cat (niggerlip?), *Ictalurus anguilla*

spotted catfish, as previously mentioned. Some distinguish two forms of niggerlip, but distinction by name was not heard.

As compared with the spotted catfish, size for size, the niggerlip, as known from our examples, has a larger and more prominent head with shorter chin barbels, the teeth on lower jaw extend back in longer and more tapering bands, the head is more fleshy, the body is decidedly slenderer behind, the color is blackish without spots, and the skin is conspicuously slimy in contrast to the usually clean integument of the channel catfish. The flesh is regarded as very inferior in quality to that of the highly esteemed channel catfish, although the local markets, at least, commonly take catfish as "catfish" without distinction in price.

The species has been identified so rarely that statements regarding its habits and abundance must be based exclusively upon the reports of commercial fishermen. A notable feature of the niggerlip fishery is its very brief seasonal duration—they are said to be taken in quantity only in June, or a little earlier toward the south, when they enter dark traps in great numbers; box traps are more effective in capture than net traps. The month of June is supposed to be the season of breeding, when the fish are running in schools. One informant said that he had seen the fish nesting in hollow logs about sawmills. At other seasons than early summer the fish are thought to be widely scattered over rough bottoms and therefore rarely caught. The specimens obtained by the author were taken in the last week of August. Presumably the niggerlips are

very vigorous fighters, for fishermen claim that they are "hard on set lines," escaping readily and doing damage to the lines.

The fish is not large, as compared with the Fulton or the yellow cat, having about the same range of sizes as the spotted cat (attaining a weight of 15 pounds). Its abundance in season makes it of distinct value to the fishermen, although, because of its slimy and emaciated appearance, it it not usually spoken of with respect.

At Lynxville, Wis., a June run of niggerlip is customary, but, like other fishes in that part of the river, it has recently appeared in less abundance than in former years. In the vicinity of Keokuk, above the dam and possibly below it also, niggerlip catfish are reported to be more abundant now than formerly.

Flathead. *Leptops olivaris* (Rafinesque)

GOUJON; YELLOW CAT; HOOSIER

This large catfish has goujon for its distinctive local name, while it shares with the other species the names of "mud cat" and "yellow cat." It attains nearly as great a size as the Fulton cat[17] and is as common or commoner at Keokuk. Unlike the Fulton

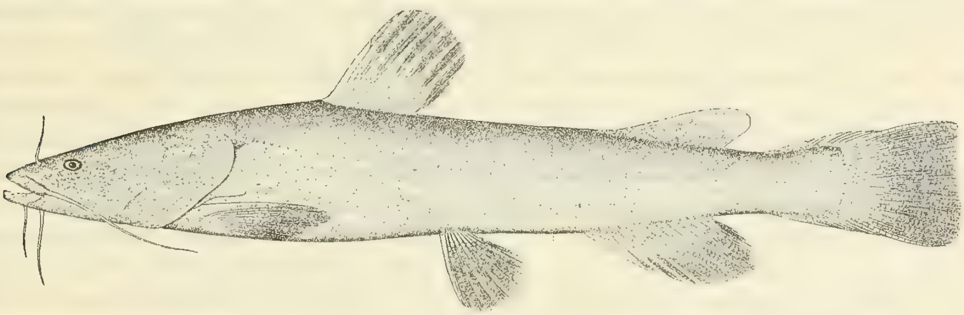

FIGURE 16.—Goujon, flathead, hoosier, or yellow catfish, *Leptops olivaris*

cat, it is taken regularly northward of that point, as far as Lake Pepin, at least. It was observed at or near Keokuk each month, except January, November, and December, but fishermen report that it is captured all during the winter. It is taken in traps but probably more frequently on set lines, and live bait is best. The fall of the year is considered the best season for "hoosiers." The flathead is described as a strong and quick fish and very predaceous, roaming in the channels but preferring the more sluggish waters. It is likely to be found about garbage dumps and the mouths of sewers, being perhaps attracted to such places by the opportunity to feed upon smaller fish of scavenger habit. It is highly esteemed as a food fish.

The goujon breeds in Louisiana and probably somewhat later than the Fulton cat. (Evermann, 1899, p. 296–298.) In 1915 two examples that were ripe or nearly so were taken in the lake within a few miles of the dam, on July 19 and 24, respectively. Nine others, examined at various places and between May 30 and June 15, contained large eggs. On June 2, 1916, eight females with well-developed eggs were seen in a market at Fort Madison, Iowa, and on June 29 one nearly or quite ready to spawn was taken in the lake near Keokuk.

[17] "This fish frequently reaches a weight of 50 to 75 pounds and is said by Doctor Evermann occasionally to weigh as much as a hundred pounds." (Forbes and Richardson, 1908.) Limits of maximum weight as given by various fishermen vary from 70 to 85 pounds.

Large goujons are taken in the lake above the dam. Some distance north of the lake, at New Boston, Ill., a pretty catch of 14 was made on September 5, 1916, the fish ranging in total length from 57 to 89 centimeters (22.5 to 35 inches.) It is said to be found in all suitable waters throughout the Mississippi Valley as well as in the Gulf States, being most abundant in the lower courses of larger streams. It is known as a fish of rivers rather than of sloughs and isolated lakes, but is associated with sluggish waters rather than with swift current. In 1890 Meek reported that it was less common in the Mississippi than in former years.

Unlike the Fulton cat, the goujon gives no sign of such a migratory habit as would be significantly affected by a barrier across the Mississippi River. In 1926 reports received at Montrose and Keokuk were to the effect that the goujon was increasing in numbers in the lake; while at Dallas City, across the lake, and at Burlington, near its upper limit, it was alleged that this catfish, especially in the larger sizes, was becoming increasingly scarce. Above the lake the species is apparently maintaining itself, except in the region of Lake Pepin and below to Lynxville, where it is reported to have declined in recent years. The yellow cat was never abundant in that region.

Other species of the family observed at Keokuk were the little stone cat, *Noturus flavus* (Rafinesque), of which a single example was taken from the stomach of a sauger on the lock gate; the yellow bullhead, *Ameiurus natalis* (Le Sueur), taken in Larry Creek and in Keokuk Lake just above the lock; and the black bullhead, *Ameiurus melas* (Rafinesque). The last mentioned is locally known as the "bullpouch" (a corruption of bullpout), the name "bullhead" being unfortunately applied to large spotted catfish. They are taken in the river from time to time, being particularly common in 1916, owing, in the opinion of fishermen, to the high stages of water connecting the sloughs with the river. While addicted to "deep and muddy streams with slowly moving current," it seems not to occur abundantly in the larger rivers. (Call, 1892; Forbes and Richardson, 1908.) An example taken near Warsaw, Ill., on April 7 was 12.5 inches in total length and weighed a pound. Its stomach contents consisted of centipede (10 per cent), May-fly nymphs (Hexagenia, 80 per cent), and débris (10 per cent).

COMMERCIAL FISHERY FOR CATFISHES

The seasonal abundance of catfishes in the region of Keokuk, as reflected by the reports of the local markets gathered by Stringham, is shown in Figure 17. It is evident that the periods of greatest catch of catfish did not coincide with the spawning season, which is in June and July, but rather began when that season was half over and continued for about six weeks. The only known factor that changed synchronously with the rise and decline of the fishery was the temperature of the water, which first passed 71° F. (21.5° C.) on June 25, rose until July 30, and then declined. In this connection, reference may be made to Evermann's report (1889, p. 292) that in Louisiana there is little fishing for catfish in summer (beginning in May) when the fish are supposed to run farther upstream or to retire to deeper water.

An increasing abundance of catfish in Lake Keokuk is well attested, by the market reports obtained by Stringham in 1916 and by the statistical surveys. (Coker, 1929.) The market receipts of catfish in summer at certain points on the lake are given in the following table, in which comparison is made with the total receipts at the same points for the whole year of 1914, the figures for that year being obtained from manuscript sheets of statistical agents conducting the survey for 1914:

TABLE 5.—*Market receipts of catfish*

Markets	1914, whole year	1916, summer months
	Pounds	*Pounds*
Montrose, Iowa (and Nauvvo in 1914)	4,800	9,000
Fort Madison, Iowa	6,900	25,400
Burlington, Iowa	11,130	7,200

The growth of the fishery, as evidenced by the reports of the statistical survey conducted by the bureau, is very pronounced—from 72,000 pounds in 1914 to 110,000 in 1917, 184,000 in 1922, and 140,000 in 1927. In Lake Pepin there was a very

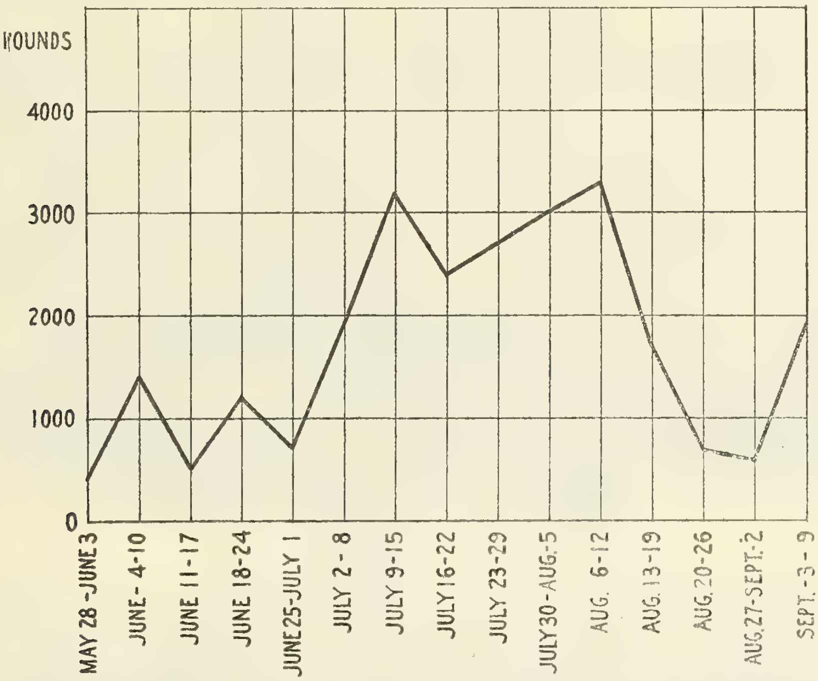

FIGURE 17.—Quantities of catfishes taken near Keokuk, Iowa, by weeks, May 27 to September 9, 1916

marked increase in yield from 1914 (27,000 pounds) to 1917 (254,000 pounds), but a reduced yield in 1922 (127,000 pounds), and a still smaller yield in 1927 (53,000 pounds). The catches in the three years last mentioned were, however, much greater than in 1914. In reference to the catch reported for 1927, it must be considered that a new factor, apparently pollution, had come to have a markedly disastrous effect upon nearly all fishes of the region of Lake Pepin.

SUMMARY AND CONCLUSIONS REGARDING CATFISHES

The catfishes are among the most valuable of the commercial fishes of the region of the Keokuk and of the Mississippi Basin generally. Three of the four important species of the river evidently breed both north and south of Keokuk and are not adversely affected by the dam. The Fulton catfish finds the dam near the limit of its range and is prevented from passing northward; but it is probable that it never extended northward of this point in substantial numbers.

No evidence was found of special abundance of catfishes at Keokuk before or during the early part of the breeding season, such as would be expected if they engaged in extensive northward migrations for purposes of spawning. It is probable that they tend to move upstream during warm weather in compensation for downstream drifting in cold weather.

The great increase in the yield of catfish from the lake apparently applies chiefly to the channel cat and the niggerlip. Reports regarding the flathead in the lake are not consistent. At any rate, the fishery for catfishes in Lake Keokuk showed marked and consistent development up to 1922, at least. Oral reports in 1926 indicate a continued upward trend for catfish in the lake, but this was not evident from the statistical report for 1927.

THE SUCKERS (Catostomidæ)

One of the most striking characteristics of the fish fauna of the whole Mississippi Valley, as Forbes and Richardson (1908) remark, is the prominence of the sucker family; and these fishes offer us one of the most difficult of problems, for the very reasons of their abundance and importance and their variety of kinds, together with the lack of distinctions between species in all statistical reports. In such statements the sucker fishes are lumped under two categories—"suckers" (covering probably a half dozen genera) and "buffalo fishes" (covering 3 species of one genus). Excluding buffalo fishes of the genus Ictiobus, we might find in the vicinity of Keokuk the blue sucker (Cycleptus, 1 species), the carp suckers (Carpiodes, 4 species), the chub sucker (Erimyzon, 1 species), the spotted sucker (Minytrema, 1 species), the fine-scaled suckers (Catostomus, 3 species), the redhorse (Moxostoma, 3 species), the pavement-toothed redhorse (Placopharynx, 1 species), and the rabbit-mouth sucker (Lagochila, 1 species). Some would be rare, if present; but of these 15 species possibly 4 or more may be of significance, and 10 were actually observed near Keokuk.

Blue sucker. *Cycleptus elongatus* (Le Sueur)

BLUEFISH; MISSOURI SUCKER

The blue sucker, the only species of its genus, is distinctive in appearance and habits, estimable for its qualities as a food fish, and in the past, at least, abundant enough to be caught in quantity at certain seasons. Its characteristic appearance, with strikingly reduced head, is well shown in the accompanying illustration. In distribution it seems to be largely restricted to two or three of the greater streams of the Mississippi Basin, in which it has been taken most abundantly in regions of swift water. It is generally rated, where known, as the best of the suckers. As to its past abundance, we have, on the one hand, the statement of Forbes and Richardson (1908, p. 66) that it "is not common in the Mississippi above the latitude of Quincy," and the remark of Meek (1890, p. 72) that it was not common in Iowa; we have, on the other hand, the oral reports of fisherman at many points on the Mississippi, as far north as Wisconsin, that until 10 or 15 years ago there were important spring runs and lesser fall runs of blue suckers. There is no occasion for surprise at the conflict of reports if it is borne in mind that it was the habit of the blue sucker to assemble in considerable numbers only for brief seasons and in the swiftest waters of the river, where, in the absence of effective protective legislation, it was comparatively easy to take them; while in other seasons they had retired to places unknown, probably the deeper parts of the river, from which they were taken only occasionally. The fish could, therefore, be known to commercial fisher-

men as abundant while regarded by scientific collectors as rare, unless by chance the collections happened to be made at the right season and in the right place. According to Forbes and Richardson (1908) it was reported to be abundant at Pittsburgh, far up the Ohio River.

At Keokuk, although few examples were seen during 1915 and 1916, one or more were observed in each month (except March) from February to September, inclusive. Only the market at Warsaw then handled more than an occasional sucker. Mr. Jackson, the proprietor of that market, said he had received as much as 500 pounds at one time during the winter of 1915–16; that he had about 500 pounds during the first half of June, 1916, about a dozen fish from then to September, and about 200 pounds in the first week of September. In former times, according to Mr. Jackson, speaking in 1926, blue suckers could be taken all the winter in the deep water below the rapids.

The blue sucker attains a length of about 30 inches and a weight of 15 pounds (or, as some say, of 25 pounds). It may be caught on set lines, in fyke nets, or in seines;

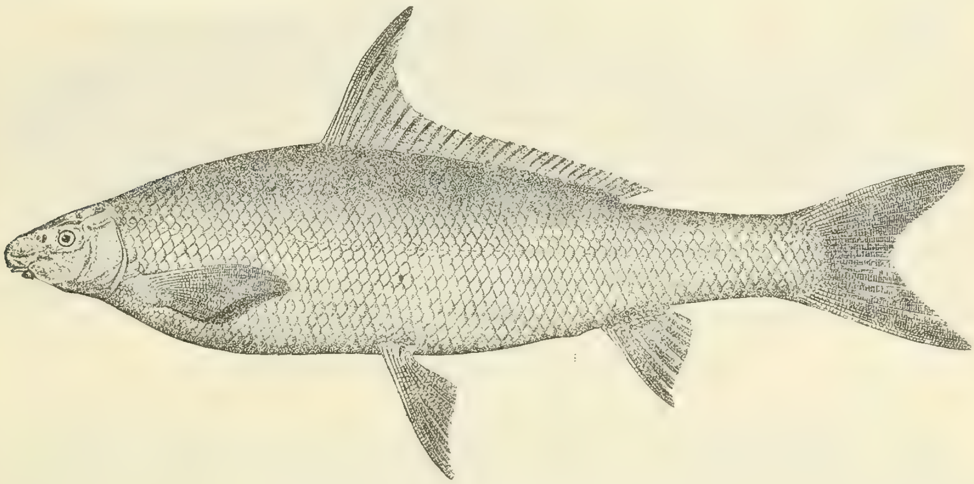

FIGURE 18.—Blue sucker or bluefish, *Cycleptus elongatus*

a favorite method of capture during the spawning migration was with the use of floating trammel nets drifted at night over the rapids; catches (with the trammel net) of 800 or 900 pounds in a night are mentioned.

Eggs are said to be deposited in May and June. (Forbes and Richardson, 1908.) Shira (1917a) mentions successful experiments in the hatching of eggs of the blue sucker at Fairport.

There was, in 1926, almost complete unanimity of opinion among fisherman as to the virtual disappearance of this fish from the upper river, although reports differ as to the manner of disappearance—whether it was gradual or sudden. It seems clear that in the region above the dam the blue sucker is only a memory. In all this region, which includes places where the fish once appeared seasonally in significant runs, practically no fisherman was encountered who reported the appearance now of more than two or three blue suckers each year.

That suckers, exclusive of buffalo fishes, have for long been of declining importance in the commercial fishery of the Mississippi Basin is indicated by the following figures from reports of statistical surveys, compiled by Sette (1925, p. 209) to show

the production of suckers from commercial fisheries of the Mississippi River and tributaries for various years.

	Pounds
1894	2,178,608
1899	2,243,934
1903	1,109,276
1908	892,000
1922	699,539

Since the general decline was more marked between 1899 and 1903 and again between 1903 and 1908 than in the longer period between 1908 and 1922, the dam built in 1913 can not be held primarily accountable for the general depreciation of the sucker fishery. As regards Lake Pepin, the yield was little less in 1917 than in 1914 but much greater in 1922. (See Table 7, Coker, 1929.) In Lake Keokuk, however, the small sucker fishery of 1914 (4,640 pounds) had almost disappeared in 1917 (700 pounds) and was not found at all in 1922. This local decline is very likely due to the changed conditions in the area covered by the lake, but its significance does not seem great.

At first thought it would seem clear that the dam has been responsible for the loss of the blue sucker from the upper river, either directly, by preventing the upward passage of fish from the lower river, or indirectly, by destroying favored schooling and breeding grounds in the rapids. Against this conclusion it may be argued that the blue sucker has largely disappeared from the lower river as well. This is a question of fact that should be determined more definitely. The limited information that we have regarding the river far below Keokuk points to that conclusion. We know that the fish is no longer common in the river from Keokuk to Canton, well below the dam. It is decidedly important that its occurrence in the Mississippi and its tributaries far below Keokuk should be investigated carefully.

River quillback. *Carpiodes carpio* (Rafinesque)

CARP SUCKER; SILVER CARP

While other carp suckers or quillbacks are occasionally found at Keokuk, the "river quillback" (*carpio*) is the only species constituting a notable fishery product. Forbes and Richardson (1908) report that the blunt-nosed carp sucker (*difformis*), common throughout Illinois, prefers the shallow waters of small streams; another species (*velifer*) is most abundant in northern Illinois; and the fourth species (*thompsoni*) is characteristic of the Great Lakes region.[18]

The river quillback is small and of minor value as a food fish. Forbes and Richardson (1908) say, regarding this species (*C. carpio*): "It is said by Mississippi River fishermen sometimes to reach a weight of 10 pounds. It is sold for food, but is flavorless and soft." In summer it is shipped irregularly from Keokuk, being said to keep badly in warm weather; in winter it constitutes a low-priced fishery product. Some fishermen say that other fish will not eat the river quillback, and it is a fact that they have not been found in stomachs of other fish during the present investigation. Forbes (1888a, p. 480) found them in the food of other fishes, but to what extent does not appear. The explanation of their not being found as food fishes at Keokuk may lie in the fact that the stomachs examined were from fish collected in the river, where young quillback are rarely found. In the fall of 1916 some were found along the

[18] Call (1892) says of *C. velifer*: "This is, beyond doubt, the most abundant of the buffalo fishes [sic!] in Iowa." He also says that it is found in rather deep but muddy waters, which is not in agreement with the observations of some others.

Illinois shore between Hamilton and Warsaw, but young were not taken in the river at any other time, although they occurred in several of the few collections that were made from creeks.

The river quillback was extremely common at Keokuk. As reported in a previous paper (Coker, 1929), it constituted 48 per cent of all fish taken in the trammel net operated on the lock gate in 1915. Its general abundance relative to other species was certainly not as high as might seem indicated by that figure, but it is believed to have been the commonest fish about Keokuk in that year, except possibly one or two minnows.

In 1916 the German carp and short-nosed gar were present in greater numbers than the year before, but the quillback was still very abundant, constituting 42 per cent of the product of 34 catches that chanced to be observed. Again the percentage figure is probably somewhat misleading, but it is believed that the quillback was exceeded in numbers by no large species except the German carp.

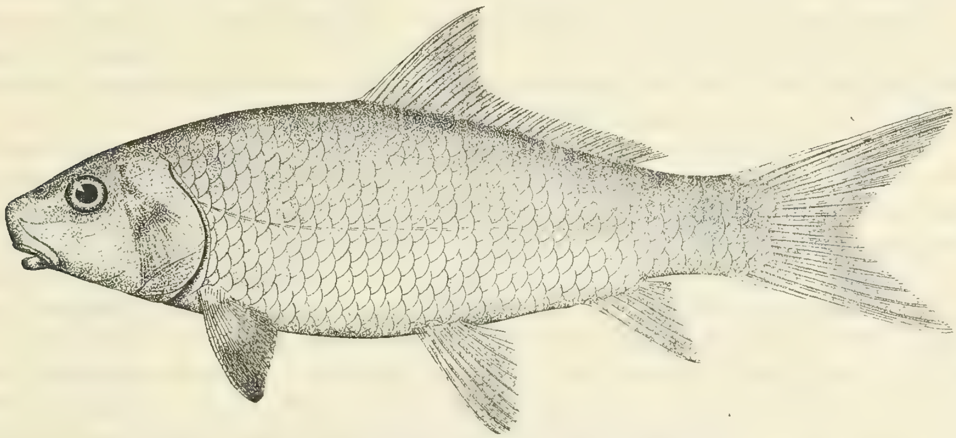

FIGURE 19.—River quillback or carp sucker, *Carpiodes carpio*

The habits of the fish seem to be unknown. It was found everywhere about the plant as well as in other localities, but never in any aggregation suggesting an interference with migratory movement. Examples were noted each month except December, during which no observations have been made. It appears to be unharmed by the dam.

In some localities fishermen distinguish "white carp" (*carpio*) and "quillback," in others "quillback" and "spearback," but the applications of the names to the respective species is not clear and is probably much confused. It is evident that there is a carp sucker most abundant in slack water (*difformis?*) and regarded as trash, and another more valuable kind (*carpio*). We must call attention to the fact that the distribution and relative abundance of the several species of carp suckers in the Mississippi River and outlying waters has not been made known but offers a promising field for study. In nearly all parts of the river the fish of one species or the other are extremely abundant. Those of substantial size (above 4 pounds) are of commercial value, usually selling as No. 1 fish, some others selling as No. 2 fish, and still others being thrown away. It is not even clear that all of the carp suckers have an indirect economic value as food of other fishes.

In the river as a whole the report is general that white carp and quillback are present in undiminished abundance; one might almost say that there is general complaint of excessive abundance, since fishermen would prefer that there should be a relatively higher degree of abundance of the more esteemed fishes, such as buffalo fishes, catfishes, sturgeon, and paddlefish.

Other suckers

The only examples of the spotted sucker or striped sucker, *Minytrema melanops* (Rafinesque), that were seen by Stringham near Keokuk were a female of 37 centimeters (15 inches) total length and a male of 36 centimeters taken in 1916 on April 18 and April 20, respectively. Both were captured in fyke nets placed in the river opposite Keokuk. They were approaching sexual maturity, the eggs being 1.3 millimeters in diameter.

But two specimens of the common sucker or fine-scaled sucker, *Catostomus commersonii* (Lacépède), were observed at Keokuk, and these were taken in the same place and way as the spotted suckers just mentioned, but on earlier dates, March 18 and 23. Each contained eggs 1.4 millimeters in diameter.

Stringham has single records for the hog sucker, *Hypentelium nigricans* Le Sueur, taken, as reported, on April 21, 1915, in a trammel net near the Illinois shore a little below Warsaw; and the white-nose sucker, *Moxostoma anisurum* (Rafinesque), found in the market of Warsaw on April 21, 1916.

The common red horse or "Des Moines plunger," *Moxostoma aureolum* (Le Sueur), is taken occasionally about Keokuk, particularly in the Des Moines River. Forbes and Richardson (1908) speak of its avoidance of turbid waters and mud bottoms and its preference for swiftly flowing streams. It is said to breed in April and May in this latitude, ascending the smaller streams and spawning on riffles. (See Hankinson, 1919, and references there cited.) The species is apparently not well adapted to the Mississippi River. As a food fish it is perhaps one of the best of the suckers.

A female from the Mississippi examined on May 1, 1915, had a total length of 16 inches and contained eggs 2.3 millimeters in diameter. Another example from the Mississippi, examined April 19, 1916, contained 2 cubic centimeters of food materials consisting of dipteran larvæ and pupæ (Simulium, 30 per cent), caddis-fly larvæ (Hydropsyche, 10 per cent), May-fly nymphs (Heptagenia, 40 per cent), dragon-fly larvæ) Gomphus, 5 per cent), and débris (15 per cent). The material was determined by Dr. R. A. Muttkowski.

The short-head red horse, *Moxostoma breviceps* (Cope), according to Forbes and Richardson (1908), has a more general distribution than the preceding species and shows a less marked preference for clear and swiftly flowing waters. At Keokuk, where the fish is called simply "red horse," it is taken in substantial numbers during the spring but very little at other seasons. The fish are captured chiefly in fyke nets placed among the willows on the Illinois side, but some are caught in trammel nets. Examples were seen in each month from January to October (except August).

In both years of observation spawning occurred during the latter half of April. Several observed on May 1 were spent fish. The eggs of mature fish 15½ and 20½ inches, respectively, in length measured 1.8 and 2.1 millimeters in diameter. Other observations of fish, mature or nearly so, revealed eggs of various diameters from 1.4 to 2.2 millimeters.

As a food fish the short-head red horse is of about the same grade as the river quillback, but it is much less abundant. It is believed that it is present about Keokuk at all times, and we have no evidence that it is significantly affected by the dam.

In general, the red horsefishes (Moxostoma) have little commercial importance in the Mississippi River, although one or more species are common in many parts of the course of the river. They are present all the year but because of poor keeping qualities are never sought in warm weather. In the cold weather of fall and spring they were frequently taken in considerable numbers in floating trammel nets or in seines. Being addicted to flowing water, they are now (1926) hardly known in the lake above the dam, although they were once abundant in the rapids at this place. It is said that before the dam was built red horse or "redfin" could be taken in quantity in winter from the Mississippi about the mouth of the Des Moines River. It was assumed that that part of the river was the winter resting place for the red horsefish that summered in the swift waters of the rapids above Keokuk and of the Des Moines River. The origin of the name "Des Moines plunger" is apparent. Although a fair food fish and saleable in season, the red horse is not highly valued; it is not large and can be sold only as No. 2 fish, as are undersized carp and quillback.

SUMMARY AND CONCLUSIONS REGARDING SUCKERS

Excluding the buffalo fishes, the suckers of most potential importance in the river are the blue sucker, the carp sucker or river quillback, and the short-head red horse. The blue sucker is a valuable food fish, lending itself to artificial propagation, and it should, if possible, be preserved as a national resource and a basis of commercial fishery. In comparatively recent years it has virtually disappeared from the upper portion of the Mississippi River, and, according to all present indications, it has largely passed from the lower river as well. There is the possibility that the dam has contributed to its loss from the upper river, but when consideration is given to the evident diminution of blue suckers below Keokuk and to the very drastic decline of the sucker fishery of the basin between 1899 and 1908, before the dam was built, the actual part played by the dam can not be fixed with any assurance.

The river quillback is probably the most abundant of all fishes in the vicinity of Keokuk and elsewhere, but it is of little economic importance. None of the suckers (disregarding the blue sucker) appear to be unfavorably affected by the dam, except in so far as the slackened current of the lake makes that particular region an unfavorable environment for fish that prefer regions of strong current.

Since 1899 the sucker fishery in the Mississippi Basin as a whole has shown a strong decline. An exception to the general trend has recently been shown in Lake Pepin, where there appeared a marked increase in the yield of suckers in 1922.

Buffalo fishes. *Ictiobus* Rafinesque (all species)

The buffalo fishes are among the most important commercial fishes of the Mississippi Basin. The value of the product to the fishermen in 1922 was over $1,000,000 (Sette, 1925, p. 208); in that year, indeed, buffalo fishes ranked above the German carp and the catfishes, the next most valuable species. In weight, the catch of buffalo fish in 1922 was a little less than that of carp.

The apparent uniformity in the catch of buffalo fish in the basin as a whole over a long period of years is quite remarkable. The figures that follow are from Sette (1925, p. 209):

	Pounds
1894	15, 924, 810
1899	14, 215, 975
1903	11, 491, 663
1908	15, 040, 000
1922	15, 488, 765

The species are not separated in statistical reports, and, indeed, it has not been practicable to do so. Some fishermen think that they distinguish five or six kinds of buffalo fishes. The majority of them name three, as do the systematic treatises. After examining many specimens, Stringham recognized the three known species but concluded that the published descriptions did not afford a satisfactory test for distinguishing between *urus* (Agassiz) and *bubalus* (Rafinesque); the ratio of depth to length was so variable as to be of little use for diagnostic purposes, but the degree of

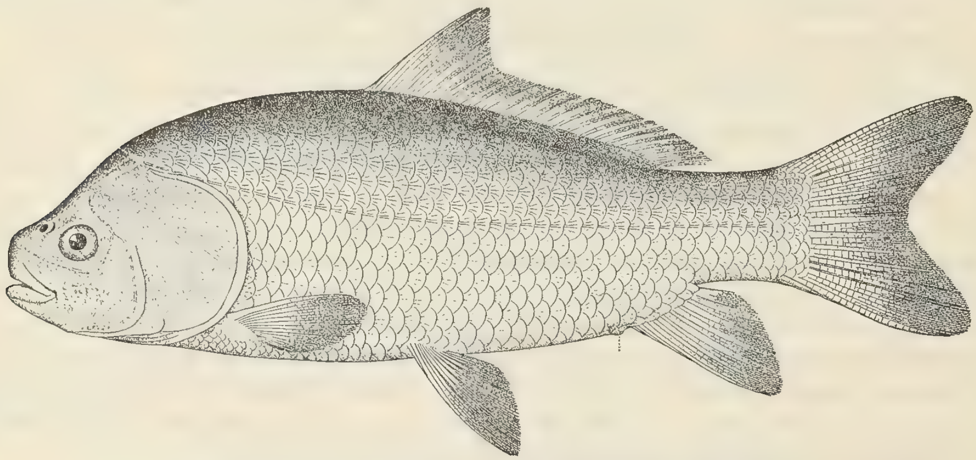

FIGURE 20.—Large-mouth buffalo fish or stubnose, *Ictiobus cyprinella*

transverse rounding of the anterior dorsal region offered a more satisfactory point of distinction.

For the reason that field identifications were sometimes doubtful, and because all statistical data and much of the information received from others was without value for application to particular species, it is not attempted in the following discussion to treat the species separately. Certain essential facts regarding the several species were established, and these will be reported first.

The two common species, the big-mouth buffalo fish, *cyprinella,* and the small-mouth buffalo fish, *bubalus*, are about equally abundant at Keokuk, while comparatively few of the "mongrel" buffalo fish, *urus*, were identified. They are all present at Keokuk practically all the time. During 1915 and 1916 *bubalus* was recorded each month except December, when no observations were made; *cyprinella*, each month except January and December; *urus*, each month except January, November, and December.

The spawning season of the large-mouth buffalo fish at Keokuk in 1916 extended from early in April to the middle of May. The small-mouth buffalo fish may have begun spawning as early, but no "ripe" fish were noted until April 21, and

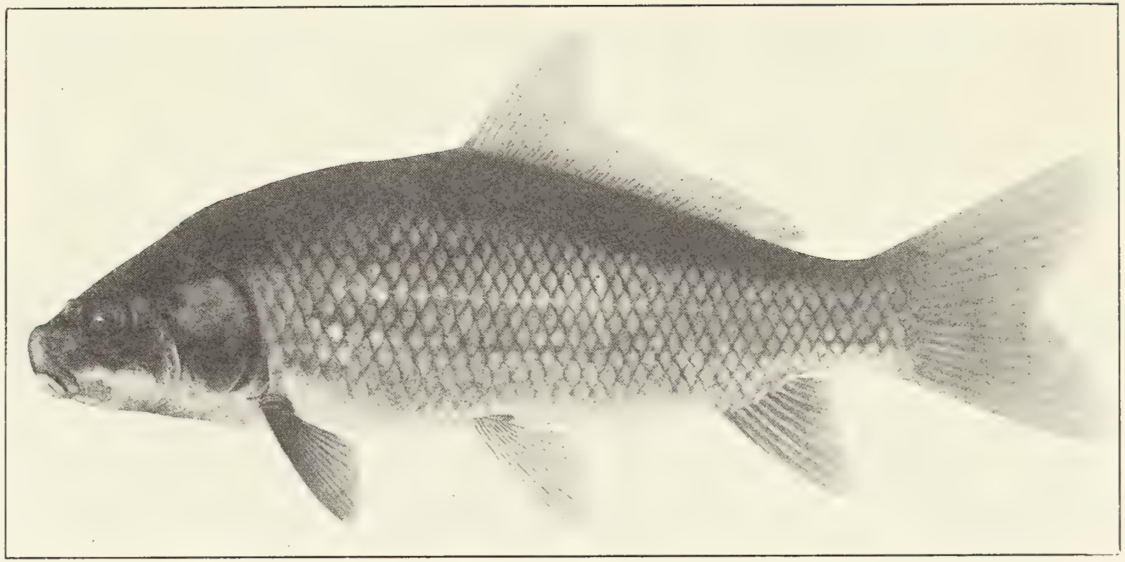

FIGURE 22.—Small-mouth buffalofish or roachback, *Ictiobus bubalus*. (Photograph from a color plate by Forbes and Richardson, 1908.)

spawning evidently concluded in the second half of May. The only ripe example of the "mongrel" buffalo fish noted that year was taken on May 17. On June 1, 1915, in a little creek then having perhaps 7 feet of water but which had been less than knee-deep a couple of months earlier, 17 buffalo fish were taken and identified in the field as *urus* and *bubalus*. All were big fish, the largest measuring 32 inches (81 centimeters) in length. Several examples, believed to include both species, were pressed and found to be "ripe." The presence of the fish in spawning condition in a small creek suggests that they sometimes ascend small streams to spawn.

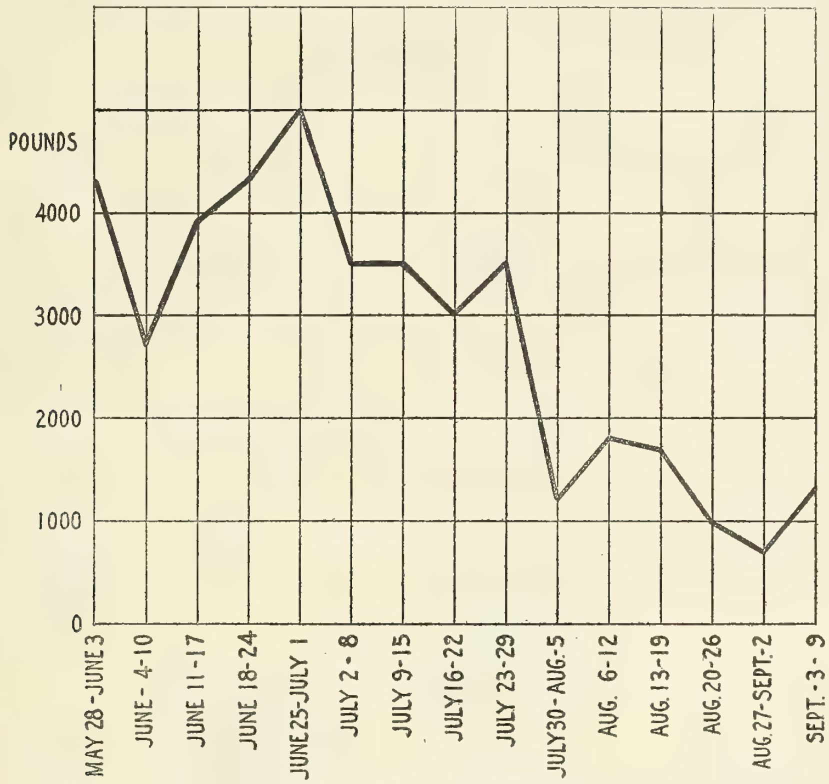

FIGURE 21.—Quantities of buffalo fishes taken near Keokuk, Iowa, by weeks, May 27 to September 9, 1916

Some indication of the relative abundance of buffalo fishes at different seasons at Keokuk may be had from Figure 21, based upon reports from the local markets received by Stringham each week during the period covered.

Considerable fluctuation in weekly catches appear, as would be expected; but in a general way the weekly catch oscillated around 3,750 pounds as a mean from about the end of the breeding season (when the record began) until the end of July. The drop about the latter date seemed in no way related to the stage of the river, which had been declining since the middle of June and continued to do so; and it was thought not to be explainable by any change in intensity of fishery, for no change was observable. It may have been related to changing water temperature, which was at its maximum just then and which declined gradually but irregularly. Possibly it was referable to the flights of May flies, the large ones of which ended at this time, although smaller flights occurred later. (See Needham, 1920, p. 272.) There is, of course, the

possibility that the fishery had depleted the local stock. In any event, the slump in catch occurred some weeks (being most noticeable at two months) after the end of the spawning season. The conditions might conform with the supposition that at some time after the spawning season the fish tend to recede down the river, so that the local spawners pass away from Keokuk, while their places are not taken by fish from the river above, since these are checked in their downward course by the slack water of the pool above the dam.

The information gained by the author in 1926 is best included at this place. It is remarkable that fishes so familiar to the fishermen of all parts of the river and so economically valuable to them should be known by such a diversity of common names. One of the chief difficulties in obtaining information regarding the buffalo fishes arises from the multiplicity of names. A special effort was made to clear up the local nomenclature, and in this I was materially helped by H. L. Canfield, whose practical knowledge of Mississippi River fishes and fishermen was invaluable. The common names applicable in one place or another to the three species of buffalo fishes severally are given below in tabular arrangement. Out of all the diversity it is apparent that the common names of *cyprinella* nearly all refer to the form of the head or the mouth, those of *bubalus* to the form of the back, and those of *urus* either to the very extensible mouth ("bugler") or to its habit of rooting in mud in the shallow waters ("rooter," "reefer," "prairie buffalo"). Names that are rarely encountered are placed in parentheses; contrasting names are placed in the same block.

TABLE 6.—*Common and scientific names of buffalo fishes of the Mississippi River* [1]

	I. cyprinella	I. bubalus	I. urus
Names referring to head or mouth.	Roundhead buffalo. Goardhead. Bullhead buffalo. Bullmouth buffalo. Bullnose buffalo. Stubnose buffalo. (Chubnose buffalo.) (Pug.) (Bigmouth buffalo.)* (Redmouth buffalo.)*	(Smallmouth buffalo.)	Buglemouth buffalo. Bugler. Rooter. Blue rooter. (Chucklehead buffalo.)
Names referring to form of back.		Roachback buffalo. Razorback buffalo. Humpback buffalo. Quillback buffalo.	Round buffalo.
Names referring to habitat.	Slough buffalo. (Mud buffalo.)	Channel buffalo. (River buffalo.)	Reefer. Prairie buffalo. Kicker.
Other names.	(White buffalo?.)	(Black carp.) Baitnet buffalo. (Southern buffalo.)	Blue buffalo. (Bastard buffalo.) (Mongrel buffalo.) (Pumpkinseed buffalo?).

[1] Some other names were encountered but were not definitely identified with a particular species. It has been said that some fishermen or dealers distinguish more than three kinds of buffalo fishes, but nearly all well-informed fishermen recognize three chief kinds, which apparently correspond with the three species known to science. The names marked with an asterisk are from Forbes and Richardson (1908).

The names used in the following paragraphs for the several species are, respectively, stubnose, roachback, and bugler. The names "roundhead" and "bullhead" are probably more generally employed for *cyprinella* than is stubnose, but either of these names invites confusion, for "round" is a very familiar name for *urus* and "bullhead" is, of course, applied to several species of catfishes.

The stubnose buffalo fish is not generally common in the river proper, being characteristically an inhabitant of the bays, sloughs, and lakes. They are less esteemed than the roachbacks and are not generally so large. Forbes and Richardson

(1908) say that the stubnose is the largest buffalo fish of the Illinois River, but conditions in that relatively sluggish stream are very different from those in the Mississippi. In the upper river, generally, the stubnose is thought to be less abundant than the roachbacks, but this may be partly because it is less sought after. It is said that in recent years the stubnose has come to supersede the other species in the river just below Keokuk, where it is taken mostly in the slack waters below the Government-built wing dams. It is the common buffalo fish of the Illinois River. (Forbes and Richardson, 1908.)

The roachback is a more migratory fish, in the opinion of fishermen. At any rate, it lives more in the current of the river and is lither in form and swifter in action. Fishermen in the region of Lake City, Minn., and Lynxville, Wis., complain of the great diminution of "humpbacks" since the dam was built. On the other hand, at all points from Fairport, Iowa, to Keokuk, this was said to be easily the most abundant species of buffalo fish; the only report to the contrary was heard at Oquakwa, where buglers were said to be equally abundant with roachbacks and at New Boston, where comment was made on an unusual predominance of the "roundheads" in that year.

The bugler is chiefly southern in distribution. It is never abundant now in the river above Muscatine but appears rather prominently in the region of New Boston and southward and just below Keokuk seems to take rank with the roachback. Mr. Canfield says that this species is much more abundant in Arkansas, where it attains a very large size.

There are several points upon which nearly all fishermen of the Mississippi River above Keokuk are in agreement. One is that buffalo fishes of very large size, 20 to 40 pounds, once common in the upper Mississippi as they are now in Arkansas (Canfield), are now very infrequent. This would be attributed more plausibly to the results of continued intensive fishery or to conditions affecting food supply (such as pollution) than to the dam. Another point of agreement is that the years 1925 and 1926 were poor years for buffalo fishes, due to stages of low water at the wrong seasons, but there was a relatively heavy catch of buffalo fishes about 1924.

The buffalo fishes and carp from Lake Keokuk command a much higher price in the large markets than do those of any other portion of the upper river. The higher value is due to the form and fatness of the lake fish.

There is in print little definite information regarding the spawning habits of the buffalo fishes. For a long time reference could be made only to a letter of A. A. Mosher to Commissioner Baird, written from Spirit Lake, Iowa, on April 24, 1885, and published in the Bulletin of the United States Fish Commision for 1885, p. 190. His vivid account is worth quoting, although the species is uncertain (it was probably *cyprinella*):

> When the water begins to grow warm after the ice goes out, these fish are around the shores in immense quantities; they are in bunches of from 3 to 7 or 8; the female is in the center, and when she sinks to the bottom to deposit her eggs, the males crowd around and under her, pushing her to the top of the water, until their tails and fins are out; then they make a tremendous rush, causing the water to foam, and with a noise which can be heard on a still evening a mile they go ahead for a few rods, then sink, and the same performance is done over. The people call it "tumbling"; in fact, it is a sight which once seen will never be forgotten.

Mosher conducted an experiment in propagation by placing the mature fish in a small basin grown over with cane grass, about 15 feet square and 18 or 20 inches deep. He removed the adult fish after spawning and recovered a large number of small fish in the fall. Nothing further seems to have been done along this line until the fish-

eries biological station at Fairport, Iowa, conducted the experiment mentioned in a following paragraph. Meantime, however, unsuccessful attempts had been made at various places to propagate the buffalo fish artificially by the mixing of eggs and sperm and the application of indoor hatchery methods. The difficulties entailed in this sort of propagation were solved by Supt. H. L. Canfield at the Fairport station in the spring of 1915, and since that time the buffalo fish has been extensively propagated by the Bureau of Fisheries in various places. The methods, which have been fully described by Canfield (1918), involve the use of special methods to avoid agglutination of the eggs, as by the use of corn starch and by brushing the eggs through bobbinet screens at different times. He tells of the taking of spawning fish in fyke nets set over inundated lands, and of the great diminution of catch whenever the water recedes, suggesting that the fish return to the river with falling water. This is a point of interest, as we shall see.

The Fairport station had also attempted to promote natural propagation of buffalo fish in ponds, but met with no success until the spring of 1917, when the conditions were varied by keeping the pond about half full of water in the early part of the season and allowing it to fill gradually early in May. A few days after the production of this artificial flood stage the splashing of buffalo fish was observed (May 11 and again May 17, 18, and 19) in overflow regions along the margins of the pond, and propagation was found to have been successful. (Shira, 1917.) The methods have been more fully described by Canfield (1922), who found that in artificial ponds it was necessary nicely to time the artificial rise of water level to the rising temperature of the water. The rise should begin when the temperature of the water is 56° F. and should be so controlled that it is completed in 10 to 15 days, with the water at 62 to 64° F. Spawning begins at 56 to 58° but is more active at 60 to 62°, so that the fish have spawned out when the rise is concluded. The large-mouthed buffalo fish (*cyprinella*) may be bred without the artificial rise, but the smallmouth (*bubalus*) does not do well without it. The rise is found desirable for both species, as the weathered grounds seem to offer a more favorable environment for the eggs during incubation. It has also been the experience of fish culturists propagating buffalo fish in the field that a normal rise in the river is beneficial (Canfield, 1918: Fisheries Service Bulletin [Culler], 1922), although it may lead to scattering of the fish and thus hamper the collectors who are seeking the spawners.

This account of the conditions of propagation has been given because the facts are not readily available and also because, in appraising the effect of the formation of a lake on the reproduction of buffalo fishes, it is important to know whether or not a normal spring flood, the effect of which would be diminished under lake conditions, is favorable or unfavorable to the multiplication of these important fishes. Apparently a rise of the river in spring, causing the water to flow out over previously exposed ground, is a positively favorable factor; but it may be that there will still be, in a pool of the nature of Lake Keokuk, a rise sufficient to meet the needs of the buffalo fishes.

From the fact that buffalo fishes are frequently taken in the current, it has been thought by some that they are migratory; a prominent fisherman in Lake Pepin spoke of "southern buffalo" as being less common than before the dam was built at Keokuk. Although buffalo fish move upstream at times, and doubtless drop back at others, and the upstream movements may normally be more vigorous when the fish are seeking spawning grounds, there seems to be no evidence at all

that any of the species are strongly migratory or that conditions at Keokuk could have any effect whatever upon the abundance of buffalo fishes at a place several hundred miles distant.

The statistics of the commercial fisheries for the years 1914, 1917, 1922, and 1927 (Coker, 1929) show a steady increase in the catch of buffalo fish in Lake Pepin—an increase, however, that is not so marked as to require any special explanation. In 1926 there was general complaint of scarcity of buffalo fishes at all places visited in Minnesota and Wisconsin, but the years 1925 and 1926 had been poor for buffalo fishes in all parts of the upper river, and apparently the same condition prevailed in 1927. The catches for the several years of report were as follows in pounds: 261,000 (1914), 301,800 (1917), 340,000 (1922), and 33,000 (1927).

The story as regards Lake Keokuk is quite different. The yield of buffalo fishes took an enormous upward jump in 1917 and showed a tremendous slump in 1922 and 1927. The figures in pounds in round numbers, are as follows: 250,000 (1914), 697,000 (1917), 114,000 (1922), and 68,000 (1927). Comment on this remarkable series of facts has already been made in a previous paper. (Coker, 1929.) We had supposed after 1917 either that the creation of the lake had made most favorable conditions for the reproduction and growth of buffalo fishes or that fish, dropping down from the upper river, collected in the lake because of the slackened current. It was naturally presumed that a permanent high level of catch in the lake was assured. It has not turned out so. It may be instructive to record some of the physical changes in the lake that occurred between 1917 and 1922.

In 1917 the lake extended out over the broad Green Bay bottoms on the western side between Montrose and Fort Madison, and these were known to be most productive fishing grounds and reputed to be the spawning ground of buffalo and other fishes. Later this whole region was formed into a drainage district and leveed, the levees, 21 miles in length from near Fort Madison to Skunk River, being closed in the winter of 1918–19. It does not appear that there are, along the whole course of the lake, any other outlying breeding grounds of adequate area. We may well question if the recovery of the overflowed lands and the old Green Bay for purposes of agriculture can yield any public benefit sufficient to compensate for the sacrifice of its value to the fisheries of the river as a whole.

In the body of the lake in 1917 there were many submerged islands still covered with the trees they had grown prior to the formation of the lake. By 1922 nearly all of the trees had disappeared, partly, perhaps, from decay, but chiefly, it is said, from being cut away in winter when they could be made into firewood and carried over the ice to the near-by villages. The flats corresponding to the islands are now almost fully exposed and open to wave action. Local informants say that buffalo fish and carp are seen abundantly in spawning activities over some of the "islands," and give it as their opinion that the nests are destroyed by the strong wave action that prevails when high winds sweep across the broad open expanses of the lake.

It may be significant that it is the catfishes that seem consistently on the increase in the lake. These are fish that can dig into banks and find or make protected places for breeding.

If a later growth of trees that endure submergence of the bases or the further growth of strongly rooted aquatic plants should give these regions protection from too vigorous wave action, probably two good purposes would be served—favorable breeding places for fish might be provided and a reduction might be effected in the

turbidity of the lake water generally and consequently in sedimentation. In any event the results of future statistical surveys may be awaited with special interest.

SUMMARY AND CONCLUSIONS

The buffalo fishes, including two or three species of the most valuable food fishes of the basin, breed far north and far south of Keokuk, and their migratory movements are presumably very limited as to length of journey along the course of the river. We find no evidence that the dam has any effect on the abundance of buffalo fishes in distant parts of the river, as in Lake Pepin, nor any marked effect on the abundance of them in the river just below the dam. The conditions as concerns these fishes in the lake above the dam seemed baffling at first. A very marked and encouraging upward trend of the fishery, as revealed by statistical data for 1917, was followed by a very discouraging decline shown in 1922. Between these dates the most extensive areas evidently suitable for spawning and nursery purposes had been reclaimed from the water for purposes of land farming, and changes had also occurred over the submerged islands away from the mainland shores, which would seemingly prevent their serving as substitute spawning grounds. The sequence of events gives the strongest reasons for assuming that the very recent decline of the commercial fishery for buffalo fishes and carp in the lake is attributable to the loss of breeding grounds. That it is lack of effective reproduction rather than of food that accounts for the decline in numbers of buffalo fish taken is further attested by the fact that the fatness of the fish from the lake gives them a notably higher value in the biggest markets. Evidently there is food enough for the fish, if not fish enough for the captors.

THE CARP AND MINNOWS (Cyprinidæ)

The minnow family is not always thought of as representing one of the chief economic assets of our waters. Yet the family is most important for two reasons: first, because it includes the carp, esteemed by some, hated by others, but always held significant; and, second, because it includes the real minnows—those "young fishes which never grow up." "It is not too much to say," we quote Forbes and Richardson (1908), "that the number of game fishes which any water can maintain is largely conditioned upon its permanent stock of minnows."

It might be supposed that, since there is such a large number of species of minnows of such varied adaptation to all sorts of ecological conditions, there could be no minnow problem in connection with a water-power development. Such a supposition would be ill founded. The author has made observations on a series of lakes resulting from a water-power development in western North Carolina, where the waters were almost entirely open, the shores and bottoms having been effectively cleared of trees and brush in almost all parts, and where, unfortunately, the conditions were unfavorable for the growth of submerged vegetation. The small streams tributary to the lakes contained minnows, but in the open waters, stocked with game fishes, there was virtually no chance for a minnow to survive and reproduce. It was reliably reported that in the first years of the lakes there had been great swarms of minnows hugging the shores and strenuously preyed upon by the game fish, which developed in numbers most gratifying to the angler. At the time of these observations practically no minnows could be found; many seine hauls in the lakes brought only the young of game fish. (Coker, 1926.) The sport-fishing in the lakes had shown a lamentable decline, doubtless because the game fish could prey only upon each other.

As regards Lake Keokuk, the conditions are quite different from those just described. Even had the trees and brush been cleared away, there are great areas sufficiently shallow and constant enough in depth to permit of the growth of submerged plants that afford the necessary shelter for minnows and other small fish. In giving special attention to other fishes we have made no adequate observations on minnows in the lake. As will appear later, two species constitute the chief minnow fauna of the river below the dam.

Carp. *Cyprinus carpio* Linnæus

"GERMAN" CARP

Despite a widespread prejudice against the carp, it remains one of the most valuable food fishes of the United States. According to statistical reports, the value of the carp product exceeds that of any other of the river fishes.

More than two-thirds of the carp product of the United States comes from the Mississippi Basin, and of this share about one-third is from the Illinois River and more

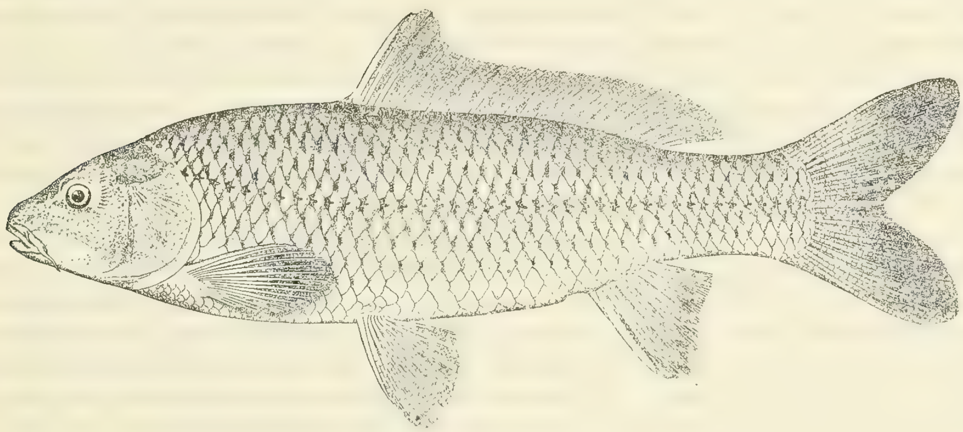

FIGURE 23.—Carp, *Cyprinus carpio*

than half from the Mississippi River itself and its minor tributaries. (See statistics in Sette, 1925.) Thus, in 1922, 9,374,073 pounds of carp were obtained from the Mississippi River itself and such tributaries as were not sufficiently significant to be named separately.

The question of the relation of carp to other fishes is one upon which so many opinions have been held and so much has been written that it would be superfluous for us to enter into a discussion of the matter, especially as we have no original contribution to make to the subject. We accept the carp as it is, standing with the buffalo fishes as paramount commercial fishes of the river.

The carp, which is supposed to have originated in Asia and which was introduced into this country from Germany, is perhaps the most adaptable of all fishes. It is found in the far south and is an important fish of the Great Lakes, especially of Lake Erie. It thrives and reproduces in rivers, lakes, and small ponds, and is, therefore, evidently without the need for extensive migrations for purposes of breeding. It is hardly necessary to ask whether the dam as an obstruction is injurious to such a fish, but the pool, with its enlarged water area, might be supposed to promote the multiplication of carp.

The statistics of the carp fisheries for Lake Pepin and Lake Keokuk since the erection of the dam are somewhat difficult to interpret. Let us first see what has been the general history of the carp fishery of the basin over a considerable period of years. (Sette, 1925, p. 209.) The product of the carp fisheries of the Mississippi River and tributaries for various years was as follows:

	Pounds
1894	1, 294, 843
1899	11, 868, 840
1903	12, 270, 346
1908	[19] 30, 670, 000
1922	[20] 18, 338, 371

There is noted a progressive increase in the carp fishery of the basin up to 1908 and a marked decline in 1922, even after discounting the figures of 1908 and 1922 because of the unusual conditions prevailing in the Illinois River about 1908.

Coming now to the consideration of recent statistics of the carp fishery of Lake Keokuk, there is found a great increase from 1914 to 1917 (from 302,000 to 762,000 pounds[21]), and a decrease of even greater proportions in 1922 (276,000 pounds), with a comparable yield in 1927 (291,000 pounds). The story is very similar to that of the buffalo fish in the same waters, except that the decline of the carp fishery was much less notable. Reference is made to the discussion of this question in connection with the buffalo fishes, page 193 above. It is the story in Lake Pepin that seems phenomenal. From 238,000 pounds in 1914 to 468,000 pounds in 1917 is not astonishing, but an increase to 2,579,000 pounds in 1922 seems to require explanation, especially as the catch in 1927 was but 615,000 pounds.

It is always proper to inquire into the validity of such statistics, and, as the story told by the records of the carp fishery of Lake Pepin appeared almost incredible on its face, a special effort was made to check it by inquiries of fishermen and dealers. The information obtained was convincing as to its essential truth. Zack Nyhart, of Lake City, Minn., informed the author in 1926 that there had been great runs of carp in 1921, 1922, 1923, and 1924, but few since. The crest of the run was, he thought in 1923. The last great haul of carp made by him was on July 30, 1924. Mr. Deschneau, of Reed's Landing, spoke of the "droves and droves" of carp of about 2½-pound weight seen in 1921 and immediately following years. He spoke of a single haul of 40,000 pounds taken in the lower end of the lake several years before (about 1922). He told also of seeing from his garden one afternoon, a great mass of carp "breaking" the water between wing dams and moving upshore. Seines were gotten ready as soon as possible, but the carp had disappeared before he and his partner were ready. Other fishermen were more successful and made large hauls from the school. From these and other reports, it appears that for some unknown reasons

[19] 15,400,000 pounds from Illinois River.

[20] 6,434,539 pounds from Illinois River.

[21] That the greatly increased yield of carp in Lake Keokuk for 1917 was not peculiar to that year is indicated by data secured from certain markets in 1916 and given below. The data of the column headed 1914 were obtained from manuscript records of the statistical agents who conducted the canvass for 1914.

Locality	1914, whole year	1916, June, July, August
	Pounds	*Pounds*
Montrose, Iowa (and Nauvoo in 1914)	22, 475	92, 000
Fort Madison, Iowa	63, 700	132, 000
Burlington, Iowa (at upper limit of lake)	81, 775	50, 000

there were about 1922, runs of carp on a scale that was probably unprecedented for the region.

As a commercial fish the carp possesses (along with the bowfin) two great advantages over other commercial fishes. It is easily kept in large numbers in pens or other forms of inclosure; consequently the fish that are caught in summer when the market is poor can be held until winter, when they can be shipped more safely and sold at a better price. They can be shipped alive at little extra expense; thousands of pounds of carp are readily shipped in cars fitted with tanks and equipped with a motor-driven pump to force air into the tanks. The motor need be employed only when the car is still, for while the train is moving the pump may be driven by a connection with the axle of the car. Live carp are, of course, in special demand in certain markets.

In 1915 carp were very numerous in the river in the vicinity of Keokuk; the only species that compared with it in abundance were the river quillback, short-nosed gar, and one or two minnows. In 1916 carp were still more numerous, those taken in the commercial fishery exceeding in weight all other kinds of fish combined. The breeding season was ascertained by Stringham's examination of about 150 examples between the middle of May and the middle of July; the first certainly mature male was found on June 2 and the last on July 13. This gives a late season, as compared with the observations of others,[22] and it may be that breeding began before June; or the breeding season may have been comparatively late because of the sl w rise of water temperature, which did not pass above 63° F. (17° C.) until May 25.

Figure 24 represents the seasonal fluctuations in catch for 1916, as determined from reports received currently from local markets. The greatest abundance in the markets coincided closely with the breeding period, occurring from about the middle of June to the middle of July, undoubtedly because the fish, as is well known, move out into shallow waters for spawning (Richardson, 1913), giving the fishermen better opportunities for capturing them. Carp were seen at Keokuk in each month except December, when no observations were made.

The observations on the carp with reference to the physical structure of the dam are significant. Owing to the habit of coming frequently to the top, and because of the brilliant yellow or orange color of the fish, it is relatively easy to observe them in the water. In the power-house inclosure, described in a previous paper (Coker, 1929) carp were seen by Stringham from time to time in 1915 from May 16 to September 24, when observations at this point were interrupted. They were also noted near the junction of the power house and the dam, and some were captured below open spillways. Among these were a ripe male taken on June 5 and two others, apparently ripe, taken on June 12. The next year, 1916, the species was phenomenally abundant in the entire vicinity of Keokuk. From May 30 until the interruption of observations after September 15 carp were usually or always to be found in the power-house inclosure. An enormous quantity was present there from about July 6 to July 15; some diminution in numbers occurred from that time onward, but there were still thousands in the inclosure by the middle of September. An extraordinary aggregation of carp near the lock is described in a following paragraph. Along the bank, between the lock and the bridge, many persons were commonly engaged in catching them with hook and line. In this short stretch 60 fishermen with hook and line were counted on the

[22] "Carp spawn in the northern United States in May and June. The eggs are small and exceedingly numerous, 400,000 to 500,000 being a common number in a 4 or 5 pound female." (Forbes and Richardson, 1908.)

evening of August 23. This fish was particularly conspicuous among the fish taken on the lock gate, constituting 90 per cent (by record) of all fishes taken that year.

The accumulation of fish in the power-house inclosure and near by seemed to indicate that the fish, at least many of them, while seeking spawning grounds, move in a generally upstream direction and so at Keokuk are checked by the power house and dam. This seemed further evidenced by the fact that the fish seen in the inclosure and near the junction of the power house and dam were frequently jumping where the water fell, as where it leaked through stop logs. Some of the leaping fish cleared

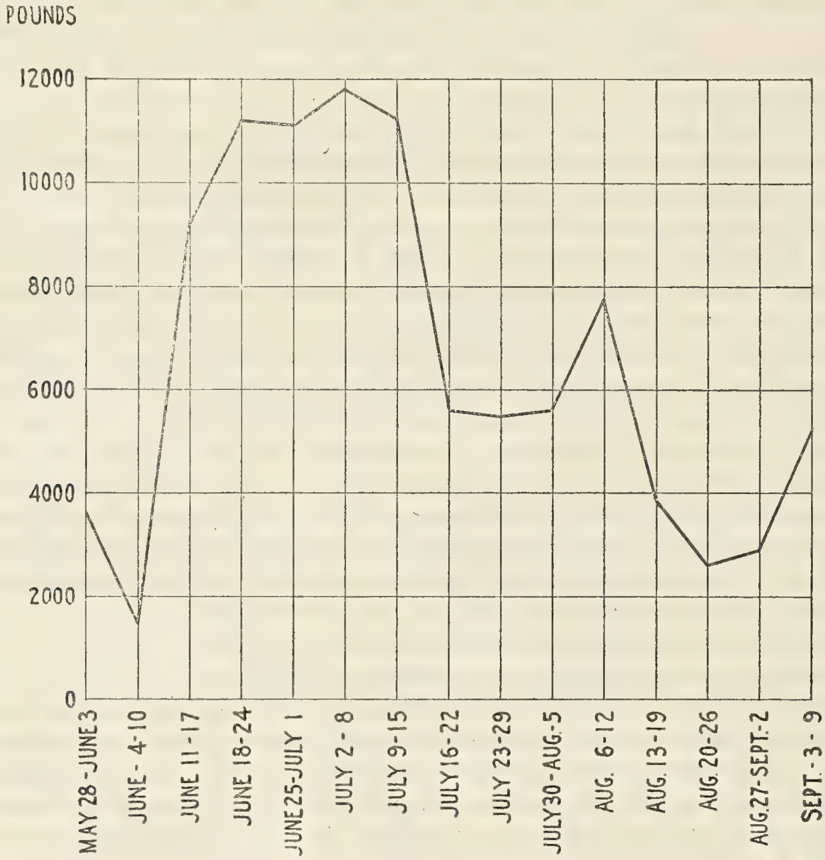

FIGURE 24.—Quantities of carp taken near Keokuk, Iowa, by weeks, May 27 to September 9, 1916

the surface of the water by a distance estimated at 1½ meters (5 feet). However, the demands of breeding could not account for the presence of fish after the middle of July, when they were generally present in somewhat reduced numbers.

The most striking accumulation of fish near Keokuk after the spring of 1914 (river herring, p. 167) was shown by carp near the lock in the middle of July, 1916. Mr. Huele, the lock master, stated that the aggregation of carp began July 16. Observations by Stringham were first made on the 17th from 2 to 5 p. m. The fish were gathered about the bottom of the chute for driftwood, situated between the lock and the lower end of the power-house structure. The number of fish in view at any given moment in this small area was variously estimated by several observers at from 4,000 to 50,000. Such estimates are significant only as indicating that the fish were seen in extraordinary numbers.

The cause of this remarkable aggregation of fish was fairly obvious. On July 13 and 14 there had occurred a great emergence of May flies, *Hexagenia bilineata*,[23] and millions were floating dead on the surface of the lake. On the 15th the prevailing wind, as shown by records of the local office of the Weather Bureau, was from the southeast, but on the 16th it came from the north and on the 17th from the northeast, driving the surface drift toward the lock and the chute, below which the carp were seen. At the time of the observation (May 17) an enormous and noisome mass of bodies of May flies, mingled with casts and with duckweed, had accumulated near the lock, and a steady stream of this matter was flowing through the chute. The carp were evidently snapping at the generous food supply. Nine carp were dipped up for examination, and although two had empty stomachs the remaining seven were found to contain duckweed and remains of adult May flies, chiefly the latter. Early the next morning, after the accumulated mass of May flies and weed had been forced out through the chute by the lockmen, both May flies and fish had disappeared. Observations could not be continued by Stringham, but the following notes made by Mr. Raber, lockman on duty from midnight to 8 a. m., are significant:

July 19. Wind *southwest.* Not more than a dozen fish visible at one time.
July 20. Wind *north.* Several hundred fish, mostly by spillway (chute).
July 21. Wind *north.* Couple of dozen fish visible at a time when there was food.

Mr. Raber's notes were found, upon inquiry from others, to be representative of the conditions throughout the period. During the remainder of the month a few carp were occasionally seen below the chute.

These observations, we think, are of real importance, because it is so generally assumed, when fish are congregated below falls or dams, that they are necessarily endeavoring to pass upstream, whereas there may be various conditions at the bases of falls to attract fish that have no decided migratory urge. Of such conditions are the exceptional degree of oxygenation of water below falls and, as in this case, the presence of food in unusual quantity.

The nomadic tendencies of carp have been commented upon by Cole (1905, p. 556–561). Another series of observations is pertinent. In 1916 carp were taken on the lock gate principally in August. The height of the movement was between August 6 and 12, but during each week of the month there were taken from three to ten times as many carp as were taken during any other week of the year. Stringham saw 300 carp shoveled from the gate on August 26. The spawning season was certainly closed before August. It should be noted that the abundance in the lock was very local, not being reflected in the catches brought to near-by markets; even the inclosure of the power house had, as already said, fewer fish in evidence during August.

From information obtained personally in 1926 it appeared that the reduced abundance of carp in Lake Keokuk, indicated by the statistical survey of 1922, still prevailed. There was general complaint along the shores of the lake of the relative scarcity of small carp. Most of the carp taken were very large. The carp of the lake, like the buffalo fishes, brought relatively high prices in the New York market. According to a reliable informant, when carp taken below the dam must be sold at 5 cents a pound those from the lake might bring 22 cents. The relative scarcity of small carp, as reported, and the fine condition of those taken in the lake bear out the supposition that the reduction in abundance of carp in the lake is attributable

[23] For details see Needham, 1920, p. 272, quoting observations of Stringham.

to unfavorable conditions for breeding rather than to lack of food supply. The fact that carp seemed to have suffered less than buffalo fishes agrees well with the fact that carp are known to be more adaptable than the other fishes. It may be added that in 1926 the reports of diminution of carp were also heard at Muscatine and Fairport. The carp taken immediately below the dam and as far as Warsaw are said to be very poor; the carp found near Canton are variable—some very good and some very "slim."

SUMMARY AND CONCLUSION

The carp, or so-called "German carp," ranks with buffalo fishes and catfishes as the most important food fishes of the Mississippi Basin as a whole and of the region of Keokuk, both in the lake and in the river below the dam. Although manifesting a tendency to move from place to place, and probably working upstream when in search of spawning grounds, its prosperity is evidently independent of *extensive* migrations, and there is no reason to suppose that the fishery can be unfavorably affected by the Keokuk development.

Up to 1917, at least, a marked increase in the abundance of carp in the lake was evident, but the statistics of 1922 (as well as those of 1927) indicate that the increased abundance was not maintained, although in 1922, and just before and after, there were notable runs of carp in the northern portion of the river. The marked decline in abundance of carp has apparently been due to changes in conditions affecting the breeding of carp and buffalo fishes. The carp and the buffalo fishes taken in the lake are said to be exceptionally fat and well flavored, so that in the large markets they command prices higher than are paid for the same species of fish from any other parts of the river. Fishermen generally complain of a relative scarcity of young carp in the region. A recent general decline in abundance of carp in the river is indicated.

Remarkable catches of carp in the region of Lake Pepin were made in 1922 and about that year, but we are not able to relate this to the presence of the dam.

There is described a most striking aggregation of carp at the dam, occurring just after the middle of July, 1916, and an obvious explanation for the condition is furnished in the mass emergence of May flies self-propagated in the lake above.

Minnows. *Notropis atherinoides* Rafinesque; [24] *Notropis jejunus* Forbes

SHINERS

About 15 species of minnows were taken in the vicinity of Keokuk in the course of the investigation, but only the two species named above were found to be present in sufficient numbers to be of evident significance in the economy of fish and man. These appeared to constitute the chief food of fish-eating fishes inhabiting the river at this point and are the principal bait fishes used by anglers. In 43 hauls of the minnow seine made from May 3 to September 2, 1916, including some from each side of the river and all being within 2 miles below the dam, there were taken 299 *jejunus*, 455 *atherinoides*, and 4 specimens of other cyprinids. Both species were found in February and in each month from April to September, inclusive. No effort was made to secure them in the other months. *Jejunus* comprised about one-third of the minnows taken in the river at Keokuk, and it was also found in the lake near Montrose

[24] Following Forbes and Richardson (1908), *N. arge* and *N. dilectus* are treated as synonyms of *N. atherinoides*. *N. rubifrons* (Cope) was looked for but not found. Changes of nomenclature suggested by Hubbs (1926) were not available at the time of our field observations, and the modification of our nomenclature at this time would be at the risk of confusion rather than clarification in our records.

and in Larry and Sugar Creeks and in the Des Moines River. More than half of the minnows taken from the river were of the species *atherinoides*, which was also found in the lake and the other waters just mentioned.

One of the methods by which minnows are captured at Keokuk shows the tendency of these fish to swim upstream, at least on some occasions. In shallow water, where the current is strong, a miniature dam is built with large stones loosely piled in a row. Near the middle of this little dam an opening is left. A conical wire net with wooden handle is then held in the opening, the open end of the net downward. If the minnows are active they will soon be striking the inside of the net, and the blows can be felt in the handle. In a little while the net is raised, emptied of its catch, and put back. Quantities of both species are caught in this way.

Minnows are found close to the power dam and were seen jumping from the water when pursued by herring. They were seen in the tailrace on May 14, 1915.

The facts noted show that minnows are probably sometimes checked by the dam and accessories while moving northward, but the observations are not extensive enough to justify conclusions. There is no evidence that the interference is of consequence.

The stomachs of eight examples of *atherinoides* were examined by Doctor Muttkowski—four contained only fragments of midges; two, fragments of May flies; one, an adult caddis fly, *Leptocella;* and one, a trace of insect débris. Stomachs of six examples of *jejunus* were also examined, with the following report: (1) Trace of débris; (2) chironomus adult fragments; (3) Probezzia sp. pupa; (4) May fly at metamorphosis, fragments; (5) May fly nymph fragments, 60 per cent, midge pupa fragments, 40 per cent; (6) caddis worm (*Leptocella*?), 50 per cent and *Lumbriculus* sp., 50 per cent.

The other species of cyprinidæ that were observed by Stringham may be listed with notes regarding their occurrence:

Campostoma anomalum (Rafinesque), stone-roller: Larry Creek, August 12–14, 1915 (2); Keokuk Lake or a tributary, September, 1915 (4 collected by Henry McAdams); Cheney Creek, March 13, 1916 (3 distended with eggs).

Hybognathus nuchalis Agassiz, silvery minnow: Mississippi River near Keokuk, September 2, 1915.

Pimephales promelas (Rafinesque), blackhead minnow: Sugar Creek, June 2, 1915 (1); Price Creek, on Iowa side, about 2 miles above the dam, April 20, 1916; Mississippi River, near Warsaw, May 6, 1916 (2).

Pimephales notatus (Rafinesque), blunt-nose minnow: Sugar Creek, April 30, 1915 (several); Larry Creek, August 12, 1915 (1).

Semotilus atromaculatus Mitchill, horned dace: Received from an angler who had caught it in a back water (or Mouth of a creek) near Hamilton, April 16, 1915 (1, length 26 centimeters, or 10¼ inches).

Notemigonus chrysoleucas (Mitchill), golden shiner: Occasionally taken in minnow seines in river. A mature female taken April 28, 1916, had a length of 15.5 centimeters, and a mature male of the same date a length of 9.3 centimeters.

Ceratichthys vigilax (Baird and Girard), bullhead minnow: Sugar Creek, April 30 and June 2, 1915; other examples received from fishermen were said to have come from the river and from Price Creek.

Notropis blennius (Girard), straw-colored minnow: After comparison with material in the collections of the bureau of Fisheries and the National Museum about 3 dozen fish, collected in Sugar Creek and the Des Moines River, have been referred to this species in spite of the fact that an inner pharyngeal tooth was found in some examples.

Notropis lutrensis (Biard and Girard), redfin: The redfin seems to be generally distributed in small numbers, having been collected in the lake at Montrose, in Larry Creek, the river below the

dam, the Des Moines River, and more abundantly in Sugar Creek. Some small specimens are slender enough to be called *N. whipplii* but are assumed to be of the same species as the larger examples.

Phenacobius mirabilis (Girard), sucker-mouthed minnow: Sugar Creek, about 2.5 kilometers from its mouth, March 22, 1916. The largest measured 7.7 centimeters (3 inches) over all and contained an earthworm in its stomach.

Hybopsis hyostomus (Gilbert): Mississippi River at Keokuk, September 2, 1915, May 25 and June 7, 1916 (3).

Hybopsis storerianus (Kirkland), Storer's chub: Several collected in the river (identification confirmed by Lewis Radcliffe); one example, 10.8 centimeters total length, taken from stomach of a goujon, April 24, 1915; Sugar Creek, March 21, 1916 (small, identified by Dr. W. C. Kendall); Mississippi River, May 19, 1916 (1).

Hybopsis kentuckiensis (Rafinesque), river chub, horny-head: Sugar Creek, March 21, 1916 (4, identified by Dr. W. C. Kendall).

THE SUNFISHES AND BLACK BASSES (Centrarchidæ)

The keenest interest of nearly all persons except commercial fishermen and market men is, of course, in the game fish, which are included chiefly in this and the follow-

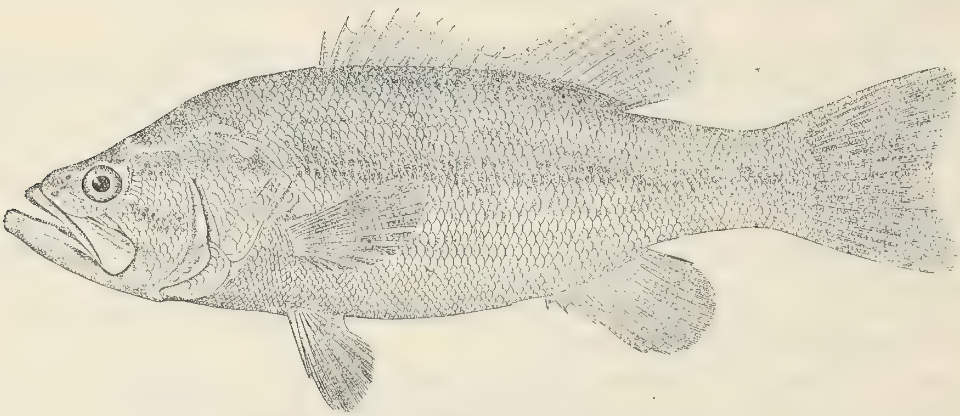

FIGURE 25.—Largemouth black bass, *Micropterus salmoides*

ing family; but, for reasons that will readily be understood when given, we have the fewest notes of direct observations to submit in reference to these fish. The natural histories of the game fishes are relatively so well known that it seemed inadvisable to give special attention to their study, except in so far as certain specific questions relating to the dam were involved. There were just two leading questions: First, does the dam as an obstruction act as an injurious barrier to upstream movements of game fish; and, second, does the lake offer them a favorable or unfavorable environment? The observations bearing upon the former question were negative and therefore are stated briefly. As to the second question, quantitative data are difficult or impossible to secure because of the general mode of taking game fish, while an effective answer to the question in terms of common information seems so clear as to admit of brief presentation.

The species of this family that are chiefly involved are the following: The white crappie, *Pomoxis annularis* (Rafinesque); the less common black crappie, *P. sparoides* (Lacépède); the bluegill or blue bream, *Lepomis incisor* (Mitchill); and the largemouth black bass, *Micropterus salmoides* (Lacépède). The white crappie was apparently about three times as abundant as the black crappie. The common sunfish of the region, large enough for table use, were practically all bluegill. Other species were

collected, chiefly the little blue-spotted sunfish, *Lepomis cyanellus* (Rafinesque), and the small orange-spotted sunfish, *L. humilis* (Girard).[25] The common black bass of the region is, as would be expected, the large-mouth; but at least two examples of the small-mouth black bass, *Micropterus dolomieu* (Lacepède), were observed. All of these are undoubtedly present all the year.

The first question stated above was this: Does the dam at any time obstruct essential upstream migrations of the members of the sunfish family? Because of the conspicuously anadromous habit of certain kinds of fish, such as the shad and the salmons, and possibly because of the fact previously referred to that other fishes sometimes congregate at the base of falls, there exists a widespread general feeling, if not a faith, that all fish must engage each year in extensive upstream migrations. We know not a single observation of any kind to suggest that such extensive migrations are an essential feature of the life history of any of the fish of this family. Crappie, sunfish, and bass are at home not only in rivers but also in lakes and in ponds, both large and small, where they thrive and reproduce year after year without the possibility of long migrations. When in rivers, no doubt, there is some downstream drifting during periods of relative inactivity and a compensatory upstream trend at times of active life in the current. There may, in many cases, be a certain leakage, as it were, from the fish supply of the upper water as fish drift unintentionally over the dam, and the leakage may require compensation.

Persistent observations failed to give any ground for the supposition that there is any considerable drainage of fish over the dam. (Coker, 1929, p. 95.) Such observation could not, of course, be continuous, and it is possible that fish pass over the dam. We would think it a desirable condition, indeed, that there should be some overflow into the river below of the game fish reared in the lake above. The most diligent observation and inquiry during a period of two years failed also to reveal any evidence of aggregation of bass or sunfish below the dam or other signs of notable upstream movement. The dam as an obstructive factor for sunfish and bass may be disregarded.

Regarding the lake as an environment for bass and sunfish, extended discussion would seem superfluous. Everyone knows that these fishes are adapted to life in lakes and ponds, and there could not well be any other expectation than that an increased area of water, much of which would be without strong current and fairly stable in level, would bring increased numbers of such fish. Bass were locally reported to have been particularly abundant in parts of the lake about 1916, a condition that is not uncommon in new lakes when young. Reference may be made to discussions in a previous paper (Coker, 1929, p. 126.)

As seen from the statistical data presented in the paper just cited, a commercial fishery for crappie and bass has been developing in the lake, but as the commercial fishery for these species is generally discouraged [26] no great development in this line is to be expected. Many persons living about the lake have testified to the author of the better fishing for such fish since the lake was formed.

A factor that will mitigate seriously against the full development of the fish-cultural possibilities of the lake is the reclamation of outlying submerged lands for purposes of agriculture. Not only is the area of the lake being thus greatly reduced

[25] The warmouth and some other species escaped notice but could undoubtedly be found.

[26] A recent act of the Congress restricts the shipment of black bass in interstate commerce. Iowa and Illinois limit the areas in which game fish may be taken in nets.

but the bottoms reclaimed are probably among those that are best adapted as breeding grounds for the common fishes. It was generally reported in 1926 that black bass were notably less abundant than in the years before the development of the Green Bay drainage district in 1919, that crappie and bluegills were apparently less affected by this development, and that warmouth or goggle-eye were never very abundant.

SUMMARY AND CONCLUSIONS REGARDING SUNFISHES

The dam as an obstruction to hypothetical upstream migrations of bass and sunfish may be disregarded. No evidence is found either of any harmful leakage of the fish supply of the upper river by the drifting of fish over the dam. The lake obviously offers a favorable environment for the reproduction and growth of bass, crappie, and bream, but its advantages in this regard are being diminished by agricultural developments involving the organization of drainage districts with the construction of levees and reclamation of submerged lands.

THE PERCHES (Percidæ)

The true perches of general interest in the Mississippi River are the yellow perch or ringed perch, *Perca flavescens* (Mitchill); the wall-eye pike, *Stizostedion*

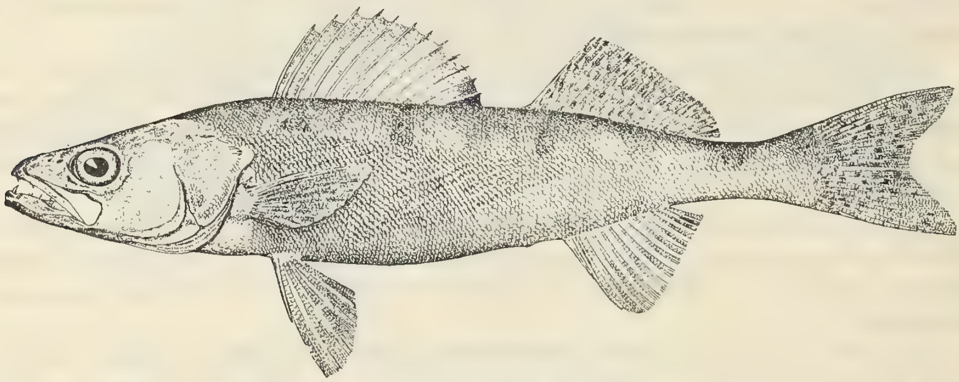

FIGURE 26.—Wall-eye pikeperch, *Stizostedion vitreum*

vitreum (Mitchill); and the sauger, *Stizostedion canadense griseum* (DeKay). The yellow perch was apparently not at all common in the vicinity of Keokuk, but, as it is "essentially a lake fish," it might become more abundant in Keokuk Lake. This had not occurred up to 1926.

The pike perches are locally but inappropriately known here, as in many other places, as "salmon" or "jack salmon." The sauger is evidently much the more common of the two pike perches. It was seen at Keokuk each month from February to October, but "salmon" of one kind or the other are known to be taken frequently in winter, probably more frequently then than at any other season. It is believed that most of the winter-caught "salmon" are saugers. Winter fishing is prosecuted with hook and line, minnows being used for bait.

In fact that pike perches are common below the dam in winter suggests the possibility of a northward migration. On the other hand, it must be kept in mind that the river just below the dam is open in winter when frozen over above and below, and also that feeding conditions are possibly better there than elsewhere. It is said, however, that "salmon" were taken most frequently in winter even before the

dam was built. We lack the information necessary to answer the question of the migratory habits of these species.

Remarks of Evermann and Clark (1920, p. 420) that are illustrative of the habits of the walleye pike in lakes may be quoted:

The walleye bites almost any time during the year, but the best season is in June and during October and November. They are occasionally taken through the ice. * * * During the warmer weather they keep in deep water. When the weather first gets cold in the fall they come inshore in some numbers at night, doubtless to feed on other fishes. * * * They do not appear to stay near shore or in shallow water during the winter, for they are not seen through clear ice, and it is not known whether they go in schools or not. From the fact that only one or a few are taken at a time it would seem that they are rather solitary.

The only mention of the breeding of sauger that has been found in the literature refers to two examples taken in Lake Champlain, N. Y., April 25. (Evermann and Kendall, 1896, p. 602.) The authors state that this indicates an earlier spawning season for sauger than for walleye. At Havana, Ill., the walleye spawned from April 1 to 15. (Forbes and Richardson, 1908.) At Keokuk six saugers taken at various dates from March 27 to May 29 were examined, and none were found advanced in sexual development; it is possible that these were spent. In 1916 an example taken on March 15 emitted milt on pressure. The breeding season and habits of the sauger offer a problem for study.

In the vicinity of Keokuk the pike perches have not been of sufficient abundance to be of commercial importance, although the beginning of a market fishery is indicated by the statistical survey for 1922, in which year 2,280 pounds were reported. Locally they are the most esteemed of the game fishes. The walleye is much the larger of the two and is of predominantly northern distribution, being a most important fish in some of the Great Lakes. It is the common "pike" of the region just south of Lake Pepin, where it is sought in the swift clear waters. It is also extensively propagated by artificial means. It is reported to be diminishing in numbers in that region where the waters are becoming less clear.

The walleye is said to attain a length of 3 feet and a weight of 25 pounds, while the sauger rarely exceeds a weight of 2 pounds. Some writers refer to the sauger as inferior in quality to the walleye, a conclusion evidently based upon observations in the north. The Missouri Fish Commission (1887, p. 118), clearly referring to the sauger, said:

The smaller and more numerous variety rarely exceeds 3 pounds; this is the better table fish of the two. As a food fish he has no superior in our waters. His flesh is white, firm, and flaky, and of most delicious flavor.

The pike perches and the yellow perch offer most unhappy examples of valuable fishery resources that during a long period of years have shown a remarkable decline in commercial importance in the Mississippi Basin as a whole. The story is plainly told in the following figures taken from Sette (1925, p. 209):

TABLE 7.—*Yield of yellow perch, pike perch, and sauger fisheries of the Mississippi River and tributaries for various years*

Year	Yellow perch	Pike perch and sauger	Year	Yellow perch	Pike perch and sauger
	Pounds	*Pounds*		*Pounds*	*Pounds*
1894	177,909	910,057	1908	36,000	133,000
1898	65,006	249,435	1922	22,250	29,395
1903	73,447	398,668			

The only break in the steady decline is found in the returns for 1903 in each case. State laws for conservation of game fishes have, no doubt, had a marked effect on the commercial fishery for these species. We can offer no other explanation for the decline except as it may be found in the changed conditions of our streams in consequence of the development of the country.

SUMMARY

Of the perches, only the sauger (locally known as "salmon") has any evident significance in the river at Keokuk. It is the most prized of local game fishes and is taken most frequently in winter by hook and line just below the dam. There is slight evidence of a developing commercial importance for the sauger in the lake. We have no adequate information regarding the possible migrations of either of the pike perches or regarding the breeding habits of the sauger. The pike perches and the yellow perch have shown a remarkable decline in commercial importance in the Mississippi Basin as a whole during the past 30 years. Other representatives of the perch family collected by Stringham in the vicinity of Keokuk were identified as follows:

Hadropterus phoxocephalus (Nelson), darter: A few samples were caught in minnow seines at and near Keokuk in both years.

Cottogaster shumardi (Girard), darter: Several specimens taken at Keokuk were secured during 1915.

Boleosoma nigrum (Rafinesque), Jonny darter: Among fish collected near Sandusky, Iowa, in Keokuk Lake and its tributaries by Henry McAdams during September, 1915, there was one Johnny darter measuring 4 centimeters total length.

Ammocrypta pellucida (Baird), sand-darter: On September 2, 1915, somewhere in the river between Keokuk and Hamilton, Luther McAdams collected an example of this species 4.9 centimeters in length.

Pœcilichthys (*Etheostoma*) *cœruleus* (Storer), rainbow darter, soldierfish: On July 29, 1915, at Cheney Creek, a specimen 4.4 centimeters in length over all was taken bulging with eggs. In September, 1915, another, 4.8 centimeters long over all, was taken in or near Keokuk Lake, near Keokuk. On March 13, 1915, in Cheney Creek, the following specimens were taken: 1 fish 5.4 centimeters long, with chironomid larvæ, mostly Chironomus, and insect débris in the stomach; 1 specimen, 5.3 centimeters in length and highly colored when fresh, containing the same kind of food; and 1 specimen, 5.3 centimeters long over all, and also brightly colored, containing chironomid larvæ, diatoms, and Mougeotia (alga) in the stomach.

A fish caught by Henry McAdams near Keokuk about June 28, 1916, belongs to this genus. It was submitted to Dr. W. C. Kendall, who reported that it was near to *E. cragini* Gilbert, but might be an undescribed species.

THE SEA BASSES (Serranidæ)

Of the great family of sea basses there are a few representatives in fresh waters, including two species in the Mississippi River. The distributions of the two species are distinct, the white bass, *Roccus chrysops* (Rafinesque), occurring northward and the yellow or striped bass, *Morone interrupta*, occurring southward; but their respective territories overlap to a considerable degree. Only the former species occurs in Lake Pepin; but the lower part of Iowa, at least, is well within the region of overlapping. Speaking of the white bass (the northern species), and with reference to the region of Quincy, Ill., a little south of Iowa, Garman (1890) wrote: "This fine species was more abundant than the striped bass [meaning *Morone interrupta*] and ranged in a greater variety of situations. I saw it caught from the swiftest current of the river." His observations referred to conditions in August, 1888. Regarding the yellow bass, he said: "Young were frequent in certain of the sloughs and lakes, but were not seen elsewhere."

At Keokuk the yellow bass, the southern species, is infrequently taken, and fishermen do not distinguish it from the other. The white bass is common although not found in great numbers. It is highly esteemed as a game fish. One fisherman

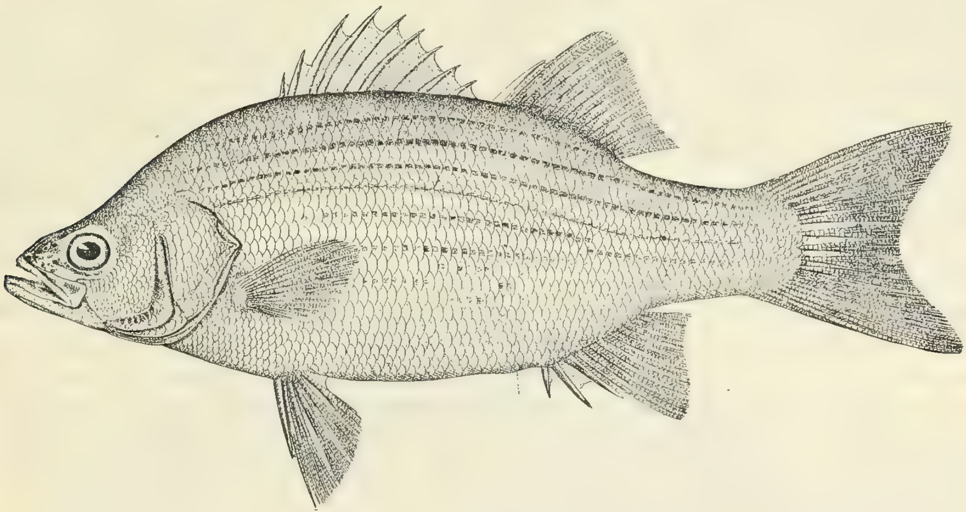

FIGURE 27.—White bass, *Roccus chrysops*

caught about 30 with hook and line on April 29, 1915. Regarding the white bass in Lake Pepin, Wagner (1908) wrote: "A common form, almost daily seen in our seines, although always in very small numbers. Many young specimens were caught with

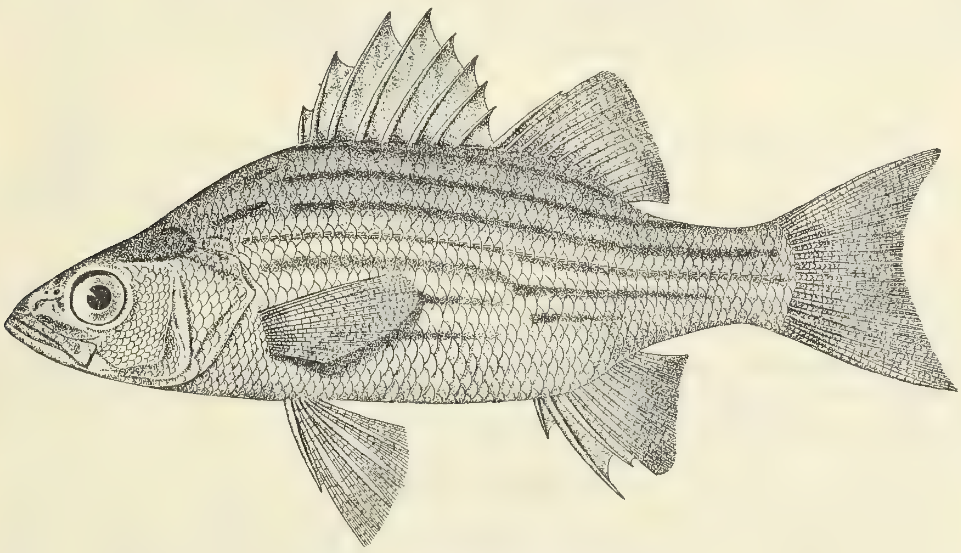

FIGURE 28.—Yellow bass, *Morone interrupta*

the minnow seine. Of all the game fishes of Lake Pepin, this one most readily takes the hook."

The white bass breeds in Michigan. (Michigan Fish Commission, 1893, p. 26) and Arkansas (U. S. Commissioner of Fisheries, 1910, p. 9.) It was seen at Keokuk

each month from March (24) to November (1), except September. During 1915 they were recorded only in spring and (once) in the fall; it is possible that they are commoner before the spawning time, but this is doubtful. At present there is no reason to consider the power development an injury to the fish. Keokuk is somewhere near the southern limit of its range, but it has been well established below the dam. Forbes and Richardson (1908) found it in Illinois "from the Mississippi near Cairo, more than 300 miles below Keokuk, to extreme northwest Illinois and thence to the Calumet River." While "its center of abundance is in the Great Lakes region * * *, it is also distributed widely over the Ohio Basin and the northern part of the Mississippi Valley." They record, however, that it was formerly much more abundant than at the time of their writing (about 1908).

So far as the information obtained orally in 1926 can be depended upon, the following conditions now apply: The white bass, formerly quite abundant in the upper part of the river, has almost disappeared within the past two or three years. In the region from Fairport to Keithsburg, above the upper limit of Lake Keokuk, the two species are about as abundant as they have been within the memory of local fishermen. From Keithsburg to Keokuk both species occur, but in comparatively small numbers. Below Keokuk white bass appear in undiminished numbers, or perhaps in increased abundance; they are taken chiefly in late fall and early spring. Yellow bass are not plentiful near Keokuk.

The history of the basses during recent decades is evidently another of the now familiar tragedies connected with the fishery resources of the Mississippi Basin. The conditions are possibly obscured a little by the fact that not only are the white and yellow basses placed in one statistical category, but there is lumped with them the rock bass, a fish of very different relationships—one of the sunfishes, in fact. The figures that follow, showing the yield of rock, yellow, and white bass from the Mississippi River and tributaries, are again those assembled by Sette (1925, p. 209).

	Pounds
1894	510, 763
1899	278, 457
1903	104, 557
1908	83, 000
1922	74, 862

SUMMARY

The white and the yellow basses occur at Keokuk, but the former is the more common species. We have no evidence of ill effect of the dam on either species and as yet no information regarding the effect of the lake. The combined yields of white and yellow basses and the rock bass (a sunfish) have shown an apparently uninterrupted decline during the past 30 years.

THE DRUMS (Sciænidæ)

The family of drums is another large group composed chiefly of marine species. The name drum is directly applicable only to those members of the family that make a croaking or drumming sound, but it fits with obvious aptness our only American species of fresh waters—the drum, sheepshead, or so-called "white perch" of the Mississippi. The equipment and method by which the drumming sound is produced in many representatives of the family is well described by Smith (1907, p. 307).

Drum. *Aplodinotus grunniens* Rafinesque

SHEEPSHEAD

Conspicuous for its abundance, its appearance in the water, and its frequent vociferous announcement of its presence, the drum is well known to all concerned with fishing in the Mississippi and its tributaries. As Wagner says (1908), writing of the drum in Lake Pepin, the peculiar sound it produces is a characteristic feature of every twilight boat ride. Its distribution is very broad: "Throughout the Great Lakes Basin and the Mississippi Valley, between the Alleghanies and the western plains, ranging from Lake Champlain to the Red River of the North, and through the Ohio Basin to Alabama, Louisiana, Arkansas, Texas, and Mexico." (Forbes and Richardson, 1908.) It is unfortunately often known and marketed as "white perch," the name perch, properly applicable to fishes of a single family, being at almost any

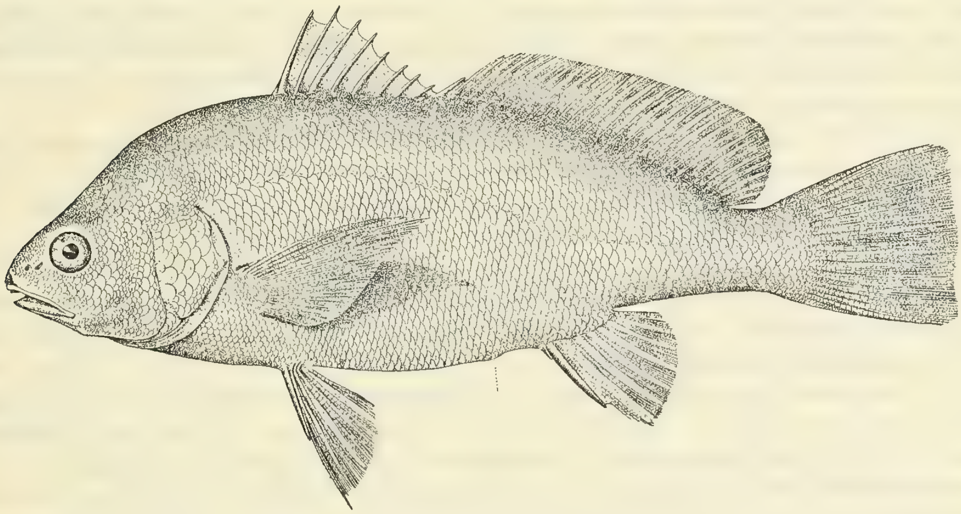

FIGURE 29.—Drumfish or sheepshead, *Aplodinotus grunniens*. (Locally but erroneously, called "perch")

place generally fitted to whatever fish seems most abundant. In many southern localities of original French influence it bears the distinctive and euphonious name of "gaspergou."

It is notable not only for its drumming sound but also for the powerful grinding apparatus (pharyngeal teeth) it possesses in the back part of its mouth and with which it may grind up the thinner-shelled mollusks that seem often to constitute the bulk of its food. Its relation to the pearly mussels that it devours is not altogether one-sided, for it thus exposes itself to infection with the glochidia (larval stages) of mussels; so that, of all fishes, it commonly carries the heaviest load of young mussels to be fostered, transported, and planted on the river bed, and then to grow up to become the food of other drumfishes. The drum is the only known fish that systematically, if unintentionally, grows its own food.

Not all of the mussels that it carries are directly valuable to man, but at least one useful species, the butterfly mussel, appears to owe its continued existence to the drum; and another, the washboard mussel, is aided by it and by other species. The drum is to be accounted a resource of double value—first, as an abundant food fish and, second, as an agent in the natural propagation of commercial fresh-water mussels, from which are made so staple an article as pearl buttons.

Although caught sometimes with hook and line and crawfish bait (Forbes and Richardson, 1908), it is primarily a market fish. In 1922 more than 5,000,000 pounds were marketed from the Mississippi River and tributaries, including the connecting Atchafalaya, and about 2,500,000 from the Great Lakes, mostly from Lake Erie, with a small quantity from Lake Huron and a much smaller amount from Lake Michigan.

As to the qualities of the fish as food there are diverse opinions. Following are some of the testimonials: Wagner (1908), Lake Pepin: "Decidedly mediocre in quality." Meek (Iowa): "A food fish of inferior quality." Woolman (1892), Kentucky: "A much valued food fish." Evermann (1902), Ohio River, Louisville, Ky.: "This fish is highly prized and meets with a ready sale." Garman (1890), Mississippi River, Quincy, Ill.: "It is considered one of the best of foodfishes." Jordan (1884): The flesh often has "a disagreeable sharklike odor, particularly in the Great Lakes, where it is never eaten." The flesh of partly grown fish is better, he says, than that of the adults. Forbes and Richardson (1908): "Thirty years ago the sheepshead was universally rejected by Illinois fishermen as worthless, but at the present time all except the largest ones are commonly dressed and sold. * * * It becomes tough and strong with age, but is at its best when weighing from three quarters of a pound to 3 pounds." Patterson (fish dealer of Dallas City, Ill.): "The perch (sheepshead) is a fine fish in Lake Pepin, but not in the Great Lakes, where it is tough; here it is soft and flaky."

The inference from these reports is that the quality of the drum as a food fish varies with its size and, perhaps, with the locality where it feeds; that only the smaller fish are good, and that those from Lake Keokuk (where the larger sizes are not yet common) are estimable fish.

Information obtained in Wisconsin and Minnesota indicates that drumfish from inland lakes are almost invariably poor and often worthless as food fish. They are said to be thin and high-backed. Thousands of pounds taken in the seines of contract fishermen are not infrequently hauled away and buried. Those from the river are usually good, and sheepshead from Lake Keokuk are considered particularly good. Very large drumfish, wherever found, are said to be quite inferior in quality.

The drum is unusually variable as to size. We have the authority of Jordan (1884) and of Forbes and Richardson (1908) that specimens of 50 or 60 pounds are not unusual; yet in the Mississippi it is not ordinarily a large fish. Garman found the largest at Quincy to be about a pound in weight. In Iowa, said Meek, it attained a length of 2 feet or more. Evermann and Kendall mention specimens from Lake Champlain that were, respectively, 28 inches long and 12.5 pounds in weight, and 19 inches long and 3.75 pounds in weight. Apparently drum 50 pounds in weight have a length of approximately 4 feet. About Keokuk it is uncommon to find drumfish weighing more than 2 pounds. One was seen on May 23, 1915, weighing 6.5 pounds dressed, and Stringham was informed of a specimen in the market on June 11 weighing 7.5 pounds dressed.

One to two pounds is the usual weight of drumfish at Fairport; less frequently examples 10 to 15 pounds in weight are found. At Lynxville it was said that most of the drumfish were 2 to 4 pounds in weight; that some of 15 to 35 pounds were taken; and, strangely enough, that drumfish between 4 and 15 pounds were extremely rare.

Regarding the natural history of the drum, more is known of its feeding than of its breeding habits. It is a fish of the larger rivers and the Great Lakes, not commonly found in the smaller streams. Jordan (1884) says: "It is apparently not at all

migratory." It thrives in the slack waters of Lake Pepin and of Lake Erie, and, according to Garman, "It seems quite at home in the swiftest current, and was caught with minnow bait from banks upon which the current strikes with a force which it would seem no animal could withstand." [27]

References to the breeding habits of the drum are almost none. Furthermore, no fisherman was found who had any information to offer on the subject. It is hardly to be supposed that a fish of such broad distribution and adaptability as to environment is geographically localized as to spawning grounds, unless it ascended small streams, such as are available from lakes or large rivers as well; but it is not found in small streams. Wagner found that in Lake Pepin "many females with ripe spawn occur by June 15." Forbes and Richardson (1908) concluded, from the condition of specimens examined by them, that in Illinois the drum "probably spawns in the latter part of May or the first of June." Circumstantial evidence indicates that it breeds in the south. Young fish 2.5 to 4.5 inches in length were frequently found in sloughs and lakes of Mississippi bottoms near Quincy, Ill., in August, 1888. (Garman, 1890.) The drum was taken at Vicksburg, Miss., in July (Hay, 1882, pp. 58, 64), not long after the probable season of spawning, and at Arthur, Tex., and Fort Smith, Ark., in May (Meek, 1894, pp. 341, 344). These last records show that the drum were present in these southern localities some time near the season of spawning. Two small drumfish, with respective lengths of 9.1 and 9.8 centimeters (3.6 and 3.9 inches), were collected by Henry McAdams in or near Lake Keokuk in September. About Keokuk in 1916, as indicated by examination of approximately 150 fish in May, June, and July, the breeding season was chiefly in the second and third weeks of June. Most of these were taken in nets placed in the unfinished half of the power house. Evidently the fish breeds in the north and in the south, but the particular places and habit of spawning of one of the commonest fishes of a large part of the country seems to be quite unknown.

Because of the dark shade of the back and the distinctive form of the tail of the drum, one can soon learn to recognize it in the water. In 1915 the drum were frequently visible near the junction of power house and dam (below spillway No. 119) from June 7 to September 13. Some were seen in the inclosure of the unfinished part of the power house on May 27 and September 5 and 7. On July 3 the power company had a large number of drum removed from this inclosure, and of four examined three contained eggs, in one instance well-developed eggs. In 1916 four small fyke nets used in that inclosure during June took 135 drum, constituting 54 per cent of the total catch of fish in the nets. None was seen from the surface near the dam until July 10, but they were thereafter noted occasionally until September. Drum ranked about fifth in abundance among the fish stranded below the dam in July, 1913. (Coker, 1914, p. 10.)

Our attention was more than once arrested by the presence of drumfish in the lock. Both in 1915 and in 1916 they ranked next to buffalo fishes and quillbacks in the numbers stranded on the lock gate. They were found there most abundantly in the former year from July 4 to 10 and September 5 to 11, and in the latter year from September 17 to 23. In the catches in the trammel net on the lock gate the drum was exceeded in 1915 by the river quillback, the spotted cat, and the Ohio shad, and in 1915 only by the two species first mentioned.

[27] It would appear that Garman either exaggerated the force of the current or underestimated the swimming abilities of many kinds of fish.

Lock Master Huele reported that when the lock was first partly filled with water and then emptied in 1915 a large number of drum were carried out; a few days later, on March 5, the first complete operation of the season was witnessed, and many drum were swept out and caught in hand nets. The fish moved their fins very feebly but appeared to be uninjured; the most likely guess is that they were hibernating and were unable quickly to resume full activity. It seems improbable that the temperature in the lock and culverts would be substantially lower than that in the river. In 1916, either because the lock had been pumped out during the winter or because the first operation was not made until March 24, only a couple of dozen drumfish were seen floating. These made frequent efforts to submerge, and some of them disappeared, while others quickly floated again to the surface. Fourteen drum taken in the lock on this day were dissected and all had the alimentary canals empty. No other species was observed to be affected by the filling of the lock.

Although particularly abundant in the neighborhood of the hydroelectric plant, the species is taken in the river generally and by all sorts of tackle. Examples were seen each month except December, when no observations were made.

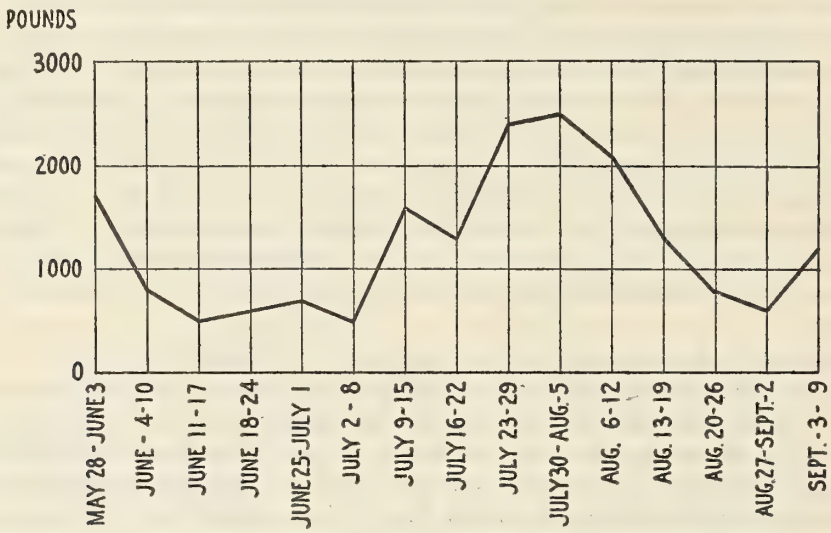

FIGURE 30.—Quantities of fresh-water drumfish taken near Keokuk, Iowa, by weeks, May 28 to September 9, 1916

A dealer at Dallas City, Ill., on the lake, spoke with assurance of spring and fall runs of drum, the fall run being then (September 29) expected to occur soon. As shown by the reports of local markets, the chief catches during the summer months were made in 1916 between July 22 and August 12. The reports, unfortunately, did not continue beyond September 9. The story for the summer is told by Figure 30. With this species, as with some others previously discussed, there was no unusual abundance during the spawning season, which evidently occurred in June.

In Lake Pepin, Minn., and Wis., the catch by the seining crew of the Un ted States Bureau of Fisheries greatly declined in 1915 and still more in 1916, as appears from Table 8. Austin F. Shira, who had charge of the work during a part of the period, stated that special efforts were made to secure the fish in 1913 and 1914, but the decline was so great as to lead us to suspect that there must be another

cause—possibly the Keokuk Dam. The statistics of the commercial fisheries indicate, however, that there was no enduring diminution of the species of the lake. The yield of the commercial fisheries of Lake Pepin in 1914 was 132,000 pounds; in 1917, 118,000 pounds; in 1922, 396,000 pounds; and in 1927, 114,000 pounds, using even thousands. As previously mentioned, the catches of all fish in 1927 and a year or two preceding were very poor in the region of Lake Pepin.

TABLE 8.—*Quantities of drumfish taken by Bureau of Fisheries seining crew, 1913–1916, Lake Pepin*

Year	Hauls made	Fish taken	Year	Hauls made	Fish taken
1913	438	32, 977	1915	476	8, 005
1914	377	32, 998	1916	384	4, 860

About Keokuk Lake no complaints were heard of the disappearance of the drum. Information gained in 1916 indicated marked increase in the catches of drum about Montrose and Fort Madison and the approximate maintenance about Burlington (at the head of the lake) of the conditions of 1914. The bureau's statistical reports show a marked development of the drum fishery from 1914 (26,860 pounds) to 1917 (160,554 pounds), but a decline in 1922 (65,040 pounds), which was very distinct although not approaching closely the lower stage of 1914. In 1926 the general report from Fairport, Iowa, to Canton, Mo., both above and below the dam, was that drumfish were as plentiful as ever; yet the statistical report for 1927 showed a decline practically to the level of 1914 (27,538 pounds).

We have recorded the lamentable story of the diminution of several of the most important fishery resources. It is pleasant to note that the drumfish, like buffalo fish, catfish, and some others of minor importance, appears to be holding its own in the Mississippi Basin generally, as shown by the records of catch that follow (figures from Sette, 1925, p. 209):

	Pounds
1894	4, 478, 620
1898	3, 149, 232
1903	2, 748, 743
1908	4, 737, 000
1922	4, 539, 165

SUMMARY AND CONCLUSIONS REGARDING THE DRUM

The drum, a low-priced food fish of the larger rivers in the Mississippi Valley and of the Great Lakes, is of best quality when of small size, and only the small sizes are common in the vicinity of Keokuk. It is valuable not only for itself but for the commercial mussels for which it serves as host. The fish evidently breeds north and south of Keokuk, but the extent to which it occurs close about the power plant suggests that this, to some extent, blocks the normal movements of the fish; these movements seem not to be related to spawning, and the fish is not generally regarded as having a pronounced migratory habit. The drum appears in the vicinity of Keokuk to hibernate and to be in greatest activity when the water is warmest. There is no evidence of diminution in abundance of drum in the river above the dam, and possibly the reverse is the case in the region covered by Keokuk Lake. On the whole, the indications are that the power plant has effected no serious injury to the drumfish in the Mississippi River. The drum is one of the few important commercial fishes that is now captured in the commercial fisheries of the basin in undiminished quantity as compared with conditions about 30 years ago.

CERTAIN FISHES OF MINOR IMPORTANCE

We may insert here some records regarding species that were rarely found.

Common pike. *Esox lucius* (Linné)

PICKEREL

Keokuk is evidently south of the common range of the true pike in the Mississippi River. The so-called "pike" of the river is, of course, the pike perch or walleye, another kind of fish (p. 204). In 1916 pickerel were recorded four times, the dates and lengths (in centimeters over all) being as follows: April 18, 49; April 25, 18.5; May 14, 29; June 19, 8.3. The last-mentioned example was brought as a curiosity to the Alexandria market and the others were caught near Keokuk and Hamilton. The fish taken April 25 was destroyed in the burning of the Fairport laboratory, having been doubtfully identified as *E. vermiculatus.* While ordinarily pickerel seem to be nowhere abundant in the Mississippi River, they were being taken in Lake Pepin in 1926 in surprising numbers, as compared with other species of fish that were very scarce.

Top minnow. *Fundulus notatus* (Rafinesque)

The only record of this species is based on a specimen caught somewhere in the vicinity of Keokuk and brought to Stringham on July 20, 1915.

Brook stickleback. *Eucalia inconstans* (Kirkland)

One stickleback, measuring 2.77 centimeters over all, was caught near the ice boom above the lock on July 11, 1916.

Brook silverside. *Labidesthes sicculus* (Cope)

Two examples were seined in Larry Creek, August 12, 1915, and in the following year, on August 22 again on September 2, single examples weie taken in the river between Warsaw and Hamilton.

Eelpout. Lota maculosa (Le Sueur)

LAWYER

The eelpout, though not seen by Stringham or by the author, has been recorded from the Mississippi River. (Wagner, 1908, Lake Pepin; Forbes and Richardson, 1908, "occasionally taken in the Ohio and the upper Mississippi.") Luther MacAdams, at Keokuk, said that he has seen as many as a half dozen examples in the vicinity of Keokuk; the description of the fish that he offered gives credence to his statement. The species is not known to most of the fishermen of the river. Mr. Kayo, of Lynxville, Wis., said in 1926 that eelpouts or "lawyers" had not been known in that region until within the past few years, but that now a good many were taken in bait nets fished in cool waters in the fall, and that they ranged in length up to 30 inches.

THE LAMPREYS (Petromyzonidæ)

Silver lamprey. *Ichthyomyzon concolor* (Kirtland)

The lamprey, while not used as food, is of economic significance as an enemy of fishes. As matter of fact, lampreys are edible. The lampreys of Europe are esteemed as food, but those of America seem not to have come into the market in any significant way. They "attach themselves to the bodies of fishes by means of the sucking

mouths, rasping off the flesh and sucking the blood of their helpless victims, which swim about unable to dislodge them. The ring muscle of the mouth works all the teeth at once against the selected surface, and both scales and skin are soon bored through. The relentless voracity of these fearful pests of our fresh waters is shown by the deep holes which they make in the living bodies of their victims and by their own intestines gorged with blood and flesh. Their hold is probably seldom loosened by any fish, unless by accident." (Forbes and Richardson, 1908.)

The paddlefish, when more abundant, were conspicuously the favored hosts of lampreys, which are said to be common on all large fishes except the game fishes. They are now seen most frequently on catfish, sturgeon, carp, and buffalo fish.

They are taken most plentifully in spring and fall and are said to found on fish caught from beneath the ice. While there are reports that lampreys are seen less commonly in Lake Pepin in recent years, they are plentiful enough in the region from Fairport to Keokuk.

FRESH-WATER MUSSELS

The report would not be complete without reference to the fresh-water mussels, which are the basis of a very important industry of button manufacture. The mussels as adults are sedentary in habit, and they can be affected directly by the power development only in the region covered by the impounded water; but the larval mussels are, in a sense, migratory, for they are parasitic on fish, which move from place to place, unwittingly conveying the young mussels and distributing them more or less widely as they fall from the gills or other parts of the fish after completing the metamorphosis from larval to adult form of body. The mussels, then, are affected as the fish are affected. The relations of the several species of mussels to the several species of fish have been fully treated in another report (Coker, Shira, Clark, and Howard, 1921), and some specific cases pertinent to this study have been mentioned in earlier pages of this report. Since most of the possible effects of the dam upon mussels are conditioned upon the effects upon fishes, it would be a redundancy to discuss the effects of the second order in detail. We will, however, refer to a few significant facts that have not been brought out previously.

The old rapids above Keokuk was a famous place for niggerhead mussels of the finest quality. The change from rapids to bed of lake at once rendered bottom conditions in that region unfavorable to that particular mussel; the ensuing sedimentation probably destroyed what mussels were there and prevented their replacement by others of different habit. F. C. Vetter, of Muscatine, told the author in 1926 that he had recently had a diver go down over the old rapids to see if the niggerhead mussels still remained. The bottom was found deeply covered with fine silt, into which the diver sank so far that Mr. Vetter was afraid to permit him to continue the search. The mussel fauna of former times is gone from that region.

There is the possibility that in other parts of the lake there may be bottoms suitable for other kinds of mussels, such as the Lake Pepin mucket, which thrives so well and proves so valuable in Lake Pepin and Lake St. Croix. For several years the Fairport station had made attempts to introduce the Lake Pepin mucket in Lake Keokuk. Some mussels from a plant made near Fort Madison by Superintendent Hessen were seen in 1926, having been recently recovered from the lake. It is very desirable that these attempts be continued, but it is by no means to be assumed that the conditions of bottom in Lake Keokuk will permit of a population

of mussels at all comparable to the fauna of Lake Pepin. The conditions of sedimentation in Lake Keokuk seem entirely different from those in Lake Pepin and quite likely are far less favorable for mussels.

In 1926 the author was greatly impressed by what seemed a remarkable change in the aspect of the mussel fauna of the river as a whole between Lake Pepin and Keokuk. Twelve years before the niggerhead mussel had been the standard shell of button manufacture and was still abundant at many places in the river, although evidently in course of gradual depletion. It is a slow-growing species, and the mussel fishery was then pursued without check. There were many other species of commercial mussels occurring in varying abundance. One of these was the yellow sand shell, which was never found in abundance. Those that were taken along with other shells were sorted out on the banks if found in numbers to justify the effort. Those that reached the factories in mixed lots of shells were picked out there. The shell was considered too valuable for use in button manufacture and was generally shipped abroad to be used for the making of novelties, such as knife handles and ornaments for umbrella handles. Its high value was based in part upon its exceptional qualities among fresh-water shells, in both form and texture, and in part upon the fact that it was never available in relatively great quantities.

In 1926 the conditions had changed. Niggerhead mussels had become scarce in most parts of the river visited and very small shells of this species seemed especially rare. This information was gained by examination of many shell piles on the river banks (piles including all shells taken) and by inquiries of shellers and manufacturers. The evidence was strong that the niggerhead mussel is not reseeding itself successfully in the river. There may be presumed to be several responsible factors, of which overfishing may be one, for the mussel is one of the slowest growth. A second factor is undoubtedly the depletion of the river herring, formerly abundant in the upper river but now relatively rare; for this the dam might be responsible. (See discussion of river herring, p. 165.) There may also be other conditions that affect this particular mussel more unfavorably than others. We present the apparent facts; a definitive explanation of causes is out of the question in view of the complexity of the conditions involved.

On the other hand, the yellow sand shell, formerly relatively scarce, had become a very common mussel by 1926 and was extensively used in button manufacture. The shell is eminently adapted for the purpose, because it has the proper texture and is of such form as to yield a very high number of blanks per ton, although it lacks the qualities of fine irridescence possessed by the niggerhead shell in its hinder part. It is a very profitable shell to use when it is had in such abundance that the cutting machines can be set for it. Furthermore, it is a species of far more rapid growth than the niggerhead. To one who had known the conditions in former years it was an occasion for surprise when small boats were seen in 1926 containing *only* sand shells. At one factory the author was shown a single heap containing 200 tons of sand shells from the Mississippi River.

For the increased numbers of sand shells there may be several causative factors. A greater quantity of gars, if prevailing, would be one factor. The chief cause may, however, be the development of a condition of stability in the areas between wing dams. These have been constructed by the Government in great numbers along almost the whole course of the upper river, with the idea of restricting the channel and causing the river to scour its main course. Away from the channel and between

successive wing dams are broad areas of shallow water, which seem to be affording now, in many places at least, just the right conditions for the growth and reproduction of yellow sand shells. It is also easily practicable in these shallow waters to collect mussels by hand while wading, and this practice, known as "pollywogging," is more extensively practiced now than in former times.

What will be the ultimate fate of the areas between the wing dams or of the bottom in the channel can be known only with the lapse of time. It is to be hoped that the shallow areas will not become completely soil filled and waterless. Such areas may be productive not only of mussels but of many living things of microscopic size, or larger, to serve as food for fishes. It is very desirable that there should be made here and there careful biological studies of the conditions between wing dams and of the contributions made by these areas to the food supply for fishes in the river as a whole. The changing Mississippi offers significant problems for study.

SOME PROBLEMS SUGGESTED

Having encountered, and sometimes quite unexpectedly, unfortunate gaps in our knowledge of the fishes of the Mississippi River and of the conditions of their existence, it seems worth while to direct attention to some of the problems that are most promising of solution with useful results. We shall refer particularly to the fishes, but may cite a few problems of more general significance. The page references given relate to earlier parts of this or the companion report [28] where the problem is first discussed. Evidently some of these problems can be attacked most profitably by Government agencies. Others, however, are readily available for naturalists suitably located with reference to rivers in almost any part of the basin.

1. A study of the varying extent and rapidity of fluctuations of river level (Coker, 1929, p. 113) should be made for the full period for which data is available. Such a study might be made for several rivers and for several points on each river.

2. There is needed a better study of the multiplication of plankton in the flowing waters of large streams like the Mississippi, and of the effect of floods in depleting given sections. (Coker, 1929, p. 124.)

3. It is most desirable that there should be a thorough study of the productivity of the shallow areas of slack waters that form between wing dams built along the Mississippi in aid of navigation, and of the contribution of such areas to the general productivity of the river. The ecological significance of such areas with reference to the river as a whole constitutes an untouched problem of great interest and importance (pp. 216 and 217).

4. The breeding habits and breeding places of paddlefish, rock sturgeon, and shovel-nose sturgeon should be better known. The rate of growth and extent of migration should be determined, especially by tagging operations (p. 142, ff; p. 150, ff; p. 152, ff).

5. There is virtually no available information regarding the habits of either of the known species of mooneyes, although one of them has real commercial possibilities. The relative abundance of the two species is known for scarcely any part of the river (p. 164).

6. The breeding habits of the river herring offer an excellent opportunity for study. The places and conditions of breeding are now entirely unknown (p. 167).

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[28] See Keokuk Dam and the Fisheries of the Upper Mississippi River, by Robert E. Coker (1929), Fisheries Document No. 1063.

This applies also to the Ohio shad, a fish of potential importance and evidently not uncommon in season, but actually recorded at only two or three places in the whole basin (p. 171). It should be sought in late spring and early summer in all large streams of the Mississippi Basin. Even records of its presence anywhere would be of importance.

7. Field studies should be made of the breeding habits of the larger catfishes. Practically nothing is known concerning the breeding of Fulton catfish, niggerlip, or goujon. What is known by direct observation of the breeding habits of the spotted catfish in fish-cultural ponds has been learned in very recent years (pp. 174, 176, 178, and 179).

8. A systematic study of the catfishes of the Mississippi, or any one of them, would be of great value. There are no adequate descriptons of any of the four larger and more important species—descriptions that give data as to change of color, form, and appearance with age, with season, or with habitat. Such information is particularly needed for the spotted catfish and the niggerlip (p. 178).

9. The condition of the blue sucker in the lower part of the river should be determined. Since it is by far the most valuable of the suckers, excluding the buffalo fishes, and since it was once very abundant and important as a commercial fishery product, further experiments in its propagation by artificial means should be made if brood fish are still obtainable anywhere. Experiments made at Fairport are suggestive of possibilities in propagation. A study of its habits in any tributary of the Mississippi would be worth while. Why is it so rapidly vanishing (p. 184)?

10. The distribution and relative abundance of the several species of carp suckers (genus Carpio) ought to be better determined; at least two species are generally obtainable in quantity in the Mississippi (p. 185).

11. The drumfish offers an excellent problem for study. It is remarkable that a fish that is so widely distributed, so very abundant, so large at times, and so valuable should be almost unknown in respect of breeding habits and natural history other than as regards its feeding habits. One may well expect to learn something of interest concerning a fish that loves the swiftest current but is at home in lakes; regarding a fish that in one place is known as a 30 to 40 pound fish, in another as almost invariably a 2 to 3 pound fish, in still another as a fish that may weigh up to 6 pounds or over 12 but rarely between; or regarding a fish that in many places is valued as a food fish and in others is discarded and burned by the ton at some expense (p. 209).

12. It is most desirable that there should be made a study of the conditions of occurrence of the yellow sand shell which is increasing in abundance in notable degree. This applies especially to the Mississippi River.

13. The conditions of the niggerhead mussel should also be ascertained more definitely—where can beds of mussels be found in the upper river, in which very young mussels of this species are present in such numbers as to promise the perpetuation of the species (pp. 166 and 216)?

14. The migration of fishes in the Mississippi River can readily be studied by means of tagging operations, such as were begun on a small scale a few years ago. The tagging and subsequent liberation of fish in large numbers is probably the most profitable method of inquiry that can now be applied to the fishes of a large river. The results should go far to settle disputed questions concerning migratory habits, besides throwing light upon rates of growth. Fishes of particular interest in regard

to migration are buffalo fishes, sauger, white bass, yellow bass, paddlefish, sturgeons, and Fulton catfish.

15. If practicable a study ought to be made of the winter habits of fishes in the Mississippi and the possible hibernation of fishes in the deeper parts at that time. Such an investigation offers considerable difficulty, however, in view of the heavy ice sheet that forms comparatively early in northern waters.

16. Strongly to be recommended is a study of the early life histories of fishes by the blanket method of towing and trawling for eggs and larval fishes and the patching together of the fragments of information gained at one time or another in different places. Such methods, applied in the sea, have been almost the chief reliance in gaining information regarding the life histories of marine fishes. Perhaps it is only by methods of this kind that the breeding habits of the paddlefish, herring, Ohio shad, drum, etc., will be learned.

17. Two suggestions regarding practical work may be repeated here. The occurrence of young eels at the base of the dam can be inquired into more particularly and consideration given to the possibility of trapping them in quantities and transplanting them to the waters above the dam, so that the upper river may be annually stocked with young eels. The transplanting of some Fulton catfish from the river below into Lake Keokuk may be worth while in the possible event that they might survive the winters in the deeper waters of the lake and replenish the river for a short distance above the lake. As the lake is about at the former northern limit of range of the species, favorable results from the experiment need not be expected with assurance.

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U. S. DEPARTMENT OF COMMERCE
R. P. Lamont, Secretary
BUREAU OF FISHERIES
Henry O'Malley, Commissioner

CONTRIBUTION TO THE BIOLOGY OF THE PACIFIC HERRING, *CLUPEA PALLASII*, AND THE CONDITION OF THE FISHERY IN ALASKA

By GEORGE A. ROUNSEFELL

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CONTRIBUTION TO THE BIOLOGY OF THE PACIFIC HERRING, *CLUPEA PALLASII*, AND THE CONDITION OF THE FISHERY IN ALASKA

By GEORGE A. ROUNSEFELL

Junior Aquatic Biologist, United States Bureau of Fisheries

CONTENTS

INTRODUCTION

NEED FOR INVESTIGATION

The herring fishery of Alaska has undergone a tremendous development in recent years. Gaining an impetus during the World War, it has increased until during the four years 1924 to 1927 an average of 160,000,000 pounds have been taken annually from the waters of Alaska. This ranks next to the take of salmon, the average annual catch of which during the same period was 358,000,000 pounds.

The rational use of this fishery and the desire to keep it at a point of maximum productivity without endangering the future supply demands a knowledge of two things: (1) We must know how the species is withstanding the strain of the fishery; (2) we must know what natural changes in abundance are occurring, so that they will not be confused with the effects of fishing, that they will be understood, and, if possible, foretold.

An investigation of the biology of the species was undertaken to understand and, if possible, to forecast these fluctuations in abundance, to discover whether they were due to natural causes or to depletion, and, if due to depletion, how this condition might best be remedied.[1] During the summer of 1925 the writer made a preliminary survey of the situation, visiting the important herring fisheries and collecting data for a general study of age and races. From an examination of these data it was decided that conditions were most favorable in central Alaska (Prince William Sound to Kodiak Island, inclusive) for working out the biology of the species, and so field work was confined to this part of Alaska in 1926.

PROBLEMS

Great natural fluctuations in abundance exist in the Atlantic herring (Hjort, 1914; Lea, 1919, 1924) and the California sardine (Higgins, 1926; Scofield, 1926). These two species, closely related to the Pacific herring, have been under observation for a number of years, and in both cases the fluctuations have been found to be due to the coming into the catch, or the departure therefrom, of fish produced in unusual numbers in some one year or years. Such an abundant year class may predominate in the catch for several years, during growth from young to adult, and as long as it is present it must increase the catch beyond that ordinarily taken. These "dominant" year groups may be one cause of the fluctuations in abundance of the Alaska herring, and if so, such fluctuations may be due largely to natural causes, not to overfishing.

To discover whether these fluctuations in abundance may be due to dominant year groups it is necessary to know the age or size composition of the herring population from year to year in order to connect any fluctuations in the catch with changes in the constitution of the population. Study of such age or size groups for a few years

[1] Many friends and associates have materially aided in the work with valuable advice and cooperation. William F. Thompson, director of investigations of the International Fisheries Commission of the United States and Canada, has aided the work in all its phases. Advice and valuable criticism have also been obtained from members of the scientific staff of the International Fisheries Commission: Henry A. Dunlop, William C. Herrington, and F. Heward Bell. I wish to thank Dr. Wilbert A. Clemens, director of the Pacific biological station of the Biological Board of Canada, for reviewing the manuscript on the section dealing with the independence of areas. To Lois F. Rounsefell I am indebted for aid in the making of counts and the tabulating and statistical analysis of data. Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries, placed at my disposal several thousand length measurements. For special aid in the field work I wish to acknowledge my indebtedness to many of the herring operators, especially to Haakon Sundsby, of Halibut Cove, Wakefield Fisheries, North American Fisheries, Utopian Fisheries, S. Sklaroff & Sons, and others.

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might make it possible to foretell coming years of scarcity or abundance. Moreover, the value of such information to the industry in indicating the extent of preparations needed for the coming season would be very great. To determine this age or size composition we have sought to make our samples represent the commercial take; but in a fishery so scattered and in which the season in a given locality may be exceedingly short, it is not only difficult to obtain a full representation of the commercial catch, but it is difficult to be certain that the commercial catch from year to year is taken from the same section of the actually existing population.

In pursuing this study it should be remembered that such knowledge must be made use of to explain the fluctuations in the catch, and that without adequate records of the catch from year to year, it may be impossible to establish and prove a definite connection between dominant year classes and unusual abundance or periods of scarcity. Until such a connection is proved to exist, and until its extent can be tested, no prophesies as to the catch can be ventured upon, and it is impossible to assume that depletion is not occurring or that the presence of dominant year classes in our samples is reflected in the catch. The trade alone can furnish such statistics to the Government.

Since the presence or absence of depletion must manifest itself through the commercial take, as evinced by the total catch or by the catch per unit of gear, reliable statistics must be obtained. At present the presumption in the public mind is that depletion occurs whenever herring become scarce in a given locality; and there is no logical way to disprove this save by advancing and proving some other explanation for a decline, such as the passage and disappearance of a dominant year class.

In determining the causes of the fluctuations in abundance one of the most important questions to be faced is that of the degree of migration, as upon that depends the relative interdependence of the populations of different regions. The existence of a single stock of herring, freely intermingling and migrating along the narrow coastal banks, would mean that any fluctuations or depletion would be widespread, and that any regulations, to be effective, would have to consider the whole coast as a unit. On the other hand, if local "races" were present, each locality would have to be treated as a separate unit, since it would then be possible to greatly reduce the supply in one area without affecting it elsewhere. A great deal thus depends on the existence or nonexistence of local "races" or populations of herring, and much of our study has been on this problem.

Whether any of the changes in abundance can be due to overfishing is a question often asked. At present our chief criterion of depletion is afforded by the statistics of the commercial catch. In some cases these statistics do not give an adequate or detailed enough picture of what has occurred, yet in a few cases the changes in abundance have been so great that they would be difficult, indeed, to obscure. However, even when a decrease in abundance is shown by statistical criteria, the conclusions drawn from them should be corroborated, if possible, by biological evidence, such as a decrease in the abundance of the older fish, a failure in areas or with types of gear depending chiefly on the schools of larger fish, or a shift in the fishing grounds. The significance of the last-named criterion will depend on the proof of the existence of separate stocks of herring in the localities in question.

Racial data have been gathered on the spawning populations, inasmuch as a comparison of the spawning populations with those comprising the main commercial catch (taken in the summer months) will show on which spawning areas each of the

races taken during the progress of the summer fishery is dependent. The spawning habits may be one of the limiting factors of their abundance; and the extent of the spawning grounds, and the number of spawners present, from time to time, may give some rough idea of the actual abundance of the herring. Overfishing should manifest itself by a decrease in the quantities of mature fish, consequently the spawning grounds should be the first to feel the effects of depletion.

The age at which the herring reach maturity has a direct influence on the amount of strain that the fishery will bear; in some fishes, as the halibut, where maturity is reached long after the fish are of a size to enter the commercial catch, there is no breeding stock that is not drawn upon by the fishery.

The preliminary nature of this report should be clearly kept in mind. In some cases the data are sufficient to warrant fairly definite conclusions, but in other cases the data are few and are presented for whatever they may show. This study will be continued indefinitely, and it is hoped that future contributions will fill in gaps and amplify the data now presented.

DESCRIPTION OF THE FISHERY

THE SEINE FISHERY

The methods of fishing have undergone considerable modification since the early days of the fishery. At that time beach seining was the method most commonly used by the small operators from Petersburg and Juneau. The only large company, that at Killisnoo, on upper Chatham Strait, used an old Norwegian method in which a large seine was placed on two boats, with about eight men per boat, the two rowing about 20 to 30 feet apart. When a school of fish was discovered they rowed around its opposite sides and pursed the seine by hand from one boat, brailing the haul into a steamer. Capt. Elling Arentsen used this type of gear for one of his boats at Big Port Walter until 1927. The seine was 14 fathoms deep and 175 fathoms long, with 1½-inch mesh, stretched measure.

Soon after 1900 the small operators of Petersburg and Ketchikan commenced using purse seines from power boats. This method of seining did not immediately supplant the Norwegian method of seining from row boats, which was continued by the Killisnoo plant until about 1924, and by the Big Port Walter plant until 1927. By 1918, however, the majority of the operators in southeastern Alaska, and all of those in the newly exploited fishery in Prince William Sound were using the power seine boats.

In 1918 the power seine boats in southeastern Alaska had an average net tonnage of 17, ranging from 11 to 31 tons. They were all powered with gasoline internal-combustion engines and carried a crew of from five to seven men. In 1927 in southeastern Alaska the purse-seine boats had an average net tonnage of 31, ranging from 20 to 42 tons, the smaller sizes having lost favor owing to their small carrying capacity. One-half of the present fleet (practically all of the newer boats) is powered with Diesel engines to cut the cost of operation. Each boat carries a crew of from six to eight men.

The purse seines employed at present range from about 175 to 250 fathoms in length and from about 12 to 30 fathoms in depth. The webbing comes in strips 3½ fathoms in width, so that the depth of a seine is easily changed by adding or taking off a strip. In the early summer, shallow seines of 4 or 5 strips are used, but in the autumn the fishermen usually have to deepen them in order to make good catches,

6, 7, and as high as 9 strips being used. The meshes are 1½ inches and occasionally 1¾ inches.

Most of the purse seining is done at night, but occasional good hauls are made in daylight, especially in the Kodiak-Afognak district. The seine boats arrive at the fishing grounds about dusk and cruise slowly about with a man always on watch. He discovers the presence of a school of herring either by seeing them "flipping" at the surface, or, if it is too dark to see, by hearing the gentle splashing. The herring "flip" best at dusk and just before dawn. Sometimes when the herring are not "flipping" the fishermen resort to "leading." A man rows slowly about in a small skiff, dragging a very fine line, to the end of which is attached a heavy piece of lead. This holds the line taut and perpendicular, so that one can tell when the line is passing through a school of herring by feeling the line jerk as the herring strike against it.

When a school of herring is located one of the crew jumps into a skiff, which the seine boat is towing, and releases the end of the seine from the seine boat. The weight of the skiff is now pulling on the seine, which commences to play out over the roller in the turntable, the man in the skiff meanwhile pulling backwards with his oars to keep the cork line tight. The seine boat sets the net in a circle and purses it as quickly as possible to prevent the herring swimming out underneath. (Fig. 1.) The net may then be hauled in slowly until the fish are crowded enough to brail into the boat with a large dip net. (Fig. 2.)

If the fish contain too much "feed" to salt immediately, or if the haul is too large for the plant to use in one day, the fish are impounded, conditions permitting. In this case the net is pulled in far enough so that the herring will not get it tangled into bags and smother themselves but not far enough to crowd them, for overcrowding causes them to lose their scales and die in the pound.

The pound has usually been placed in readiness beforehand, and the seine boat blows its whistle to summon its towboat to come and tow it to the pound. The towboat may be almost any small gas boat or discarded seine boat. A bridle is attached to the bow and stern of the seine boat and it is towed sideways toward the pound dragging the seine full of herring. On reaching the pound the edge of the seine is attached to the edge of the pound, the two cork lines are held below the water, and the seine pulled into the boat, forcing the herring into the pound. There are usually a number of seine boats fishing on the same ground, so that whenever one makes a set it turns on a red light as a warning to other boats not to run over the seine. These lights are usually arranged to help the towboat in identifying its own seine boat in the dark.

If the herring contain "red feed," which is composed of small crustaceans, they are left a few days in the pound before being used. This gives them time to clean themselves of the feed which would otherwise cause them to spoil when pickled. Occasionally the herrings' stomachs contain "black feed" composed of pteropods. When this is the case they are extremely difficult to cure, even after several days in the pound, and do not bring the highest prices.

By impounding herring the plants are able to have a constant supply of fish, which enables them to make a larger pack. However, impounding has disadvantages from the standpoint of conservation. When the wind and tide are unfavorable, or when the haul is made too far from the pound, there is great danger of the herring

being smothered by being forced into dense masses during the towing. In some cases the pounds have been placed in water too shallow and the receding tide has left the herring stranded. Occasionally storms drag a pound ashore, smothering the herring. Even with the best of care a small percentage of the impounded herring will soon die from infection where the scales have been rubbed off against the web.

The herring pounds are of 1¾ or 2 inch mesh (stretched measure) and of heavier web than the seines. Since they must be left in the water for a long time, they are never tanned but are heavily tarred. They are simply strips of webbing about 80 fathoms in length, put out to form a square with floats on the top and weights underneath to keep the web on the bottom.

THE GILL-NET FISHERY

In Alaska gill nets are used chiefly in Halibut Cove and a few scattered localities such as Simeonof Bay in the Shumagin Islands. (Fig. 3.) Those used at Halibut Cove are 50 fathoms in length and 100 meshes (about 3 fathoms) in depth and are anchored in one spot while fishing. The mesh used is supposed to be 3 inches across (stretched measure).[2]

Since herring seldom gill in daylight, the nets are usually let down at night. The gill nets, or set nets, as used at Halibut Cove, are anchored at both ends and kept up with buoy kegs. In the morning it is usual to lift the net, to go along it shaking the herring into the boat, and then to drop the net back into the water so that on reaching its far end it has been reset.

Gill netting is advantageous where the fish are desired for salting and where the majority of the herring are too small for pickling, since, if a proper size of mesh is used, only the larger herring are captured.

Some have ascribed the failures of the herring fishery in the various localities of central Alaska in recent years to the inability of the gear to catch the herring, except when they come into the bays. Some of the proponents of this theory have made attempts in Alaska to gill-net herring by the European method, in which a large power vessel operating at a distance from shore puts out a very long cable buoyed up at intervals with kegs. To this cable are attached a number of gill nets. Neither the boat nor the cable are anchored while fishing, hence the name "drifting" is applied to this method.

The power schooner *Decorah* attempted this method in Prince William Sound in 1924, but had no success. In 1928 the power schooner *Roald Amundsen*, equipped with 40 gill nets, each 12 fathoms long by 300 meshes deep, "drifted" all summer on the Portlock and Albatross banks, off the Trinity Islands, in Shelikof Strait, all around Kodiak Island inshore and offshore, and in Cook Inlet. This attempt also met with failure. These failures would seem to bear out the evidence of our racial investigations; that the herring, being divided into a number of local races, can not be found in any large body offshore.

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[2] Koelz (1926) made experiments illustrating the difference in effectiveness of nets which differ only ¼ inch in size of mesh. In two experiments in Lake Ontario he found that gill netting of 2½-inch mesh caught double the number of fish of netting with 2¾-inch mesh.

This is significant in that there is a distinction between meshes as manufactured and as fished. The 9 or 12 thread cotton gill netting used in Alaska shrinks in tanning and in the water. Thus the 3-inch mesh cotton gill netting used at Halibut Cove is 3 inches as manufactured, but is almost invariably 2¾ inches as fished.

FIGURE 1.—Purse seining for herring in Red Fox Bay, Shuyak Strait. This tiny bay was a heavy producer of herring from 1924 to 1926. Thirty purse-seine boats gathered here for the opening of the season on July 15, 1926

FIGURE 2.—Brailing herring from the pound into the seine boat at Dutch Harbor

FIGURE 3.—The type of small saltery used in the gill net fishery at Halibut Cove, Kachemak Bay

LOCALIZATION OF BRANCHES OF INDUSTRY

In Alaska herring are utilized mainly in four ways: For oil and fertilizer or fish meal, for pickling, for halibut bait, and for dry-salting, and the requirements vary accordingly. It is found that particular localities are favored for each of these phases of the herring industry.

The oil and fertilizer industry requires a fairly constant and cheap supply of fat herring. Cheapness implies that they are too small to be used for pickling, necessitating that small herring be more abundant at times than large herring for the industry to be profitable.

The pickled (or salted) herring industry utilizes, as a rule, only herring of over 10½ inches in total length. The herring must be fat and are much better if free from feed, as it causes the pack to spoil.

For halibut bait the herring are best in the winter and spring months, when they are thin and firm, as they stay on the hooks longer and keep much fresher than when fat. Medium sized or small herring are preferred.

For dry-salting the herring are best in the late fall and winter months, as they must be free from feed or fat, and should have the milt and roe developed. The size makes but little difference as long as they are mature fish.

The oil and fish-meal industry centers in Chatham Strait and is found to some extent in Prince William Sound, but is entirely lacking farther west. This distribution results from the large, fairly constant supply of small fat herring in Chatham Strait from June to October, and the predominance of small herring in Prince William Sound in the early summer. In southeastern Alaska the small herring so predominate as to make pickling unprofitable except as an adjunct to the oil and fish-meal industry. In Prince William Sound the schools of herring are so mixed in size that it is necessary for the plants to maintain reduction works to utilize the enormous waste, yet the supply has not been large enough to encourage the manufacture of oil and fish meal as an independent industry. All of the larger establishments in this district operate reduction plants in conjunction with their salteries. Farther west than Prince William Sound most of the herring are large enough for pickling, leaving only a small residue for reduction, while the plants are practically all either floating salteries or very small shore plants, with no room for the operation of fertilizer plants. For these various reasons no reduction plants have been operated west of Prince William Sound.

The pickled (or salted) herring industry is of greatest importance in western Alaska and the Kodiak-Afognak and Cook Inlet districts, owing to the large herring obtained in these areas. In Prince William Sound it is of about equal or of slightly greater importance than the reduction industry, but is a minor industry in southeastern Alaska.

The bait industry centers in southeastern Alaska, for it is here that the halibut boats land most of their catches. During the summer months the halibut vessels obtain fresh bait from the herring plants, but in the spring and fall months, when the herring plants are not operating, the supplying of fresh bait to the halibut fleet is a separate industry. A supply of bait is frozen during these months, when the herring are thin, and sold to the boats during periods when fresh bait is unobtainable.

At present the dry-salting of herring is of very minor importance, being carried on only in Cook Inlet in the late fall and early winter months.

HISTORY OF THE FISHERY

DEVELOPMENT OF VARIOUS PHASES OF THE INDUSTRY

The first commercial use to which herring were put in Alaska was the manufacture of oil and fertilizer. A plant for this purpose was established on the site of an old whaling station at Killisnoo on upper Chatham Strait in 1882. This was the only herring reduction plant in Alaska until 1919, in which year there were 3 on Chatham Strait. In 1920 there were 7 on Chatham Strait and 2 in Prince William Sound. In 1921, due to the low price of herring oil, only 3 of the 9 reduction plants operated—2 in southeastern Alaska and 1 in Prince William Sound. By 1923 the price of herring oil had risen to such an extent that the industry boomed until, in 1927, there were 25 herring reduction plants in the Territory—18 large plants in southeastern Alaska and 7 smaller plants in Prince William Sound. Over 100,000,000

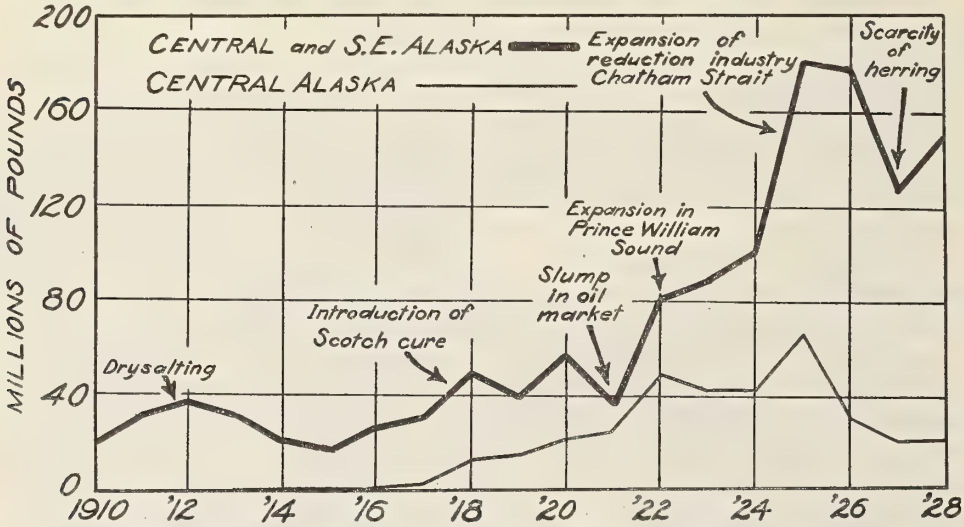

FIGURE 4.—The total catch of raw herring in central and southeastern Alaska from 1910 to 1928, inclusive

pounds of raw herring have thus been utilized annually since 1925, the peak being reached with 150,000,000 pounds in 1926.

Although a few barrels of herring were salted in various localities previous to 1900, the pickling industry may be said to have commenced about that time at Petersburg. Instead of building shore plants the fishermen packed on scows, which they towed about from place to place with their power boats, extending their operations as far as Chatham Strait by 1916. (Fig. 5.) During these years the herring were practically all packed by the Norwegian method, in which the herring are heavily salted, poorly gutted, and not carefully graded into sizes. For these reasons, and because of careless packing, the market remained very restricted. In 1917 the United States Bureau of Fisheries introduced into Alaska the Scotch method of curing herring, in which the herring are carefully graded into sizes, properly gutted, salted lightly, and neatly packed into barrels.

The attractive pack and war prices stimulated the industry, resulting in the building of several large salteries in Chatham Strait and in Prince William Sound in 1918. (Fig. 6.) Over 100,000 barrels of herring were salted in Chatham Strait, but partially on account of the war ending, and partially on account of the careless

FIGURE 5.—The type of small seine boat and floating saltery prevalent in Chatham Strait about 1917

FIGURE 6.—A typical herring saltery and reduction plant in Evans Bay, Prince William Sound

salting of the 1918 pack, a great slump occurred in the market. A good share of the 1918 pack was sent to the reduction works in Seattle and it took over two years for the pickling industry to recover. In the meanwhile it had become firmly established in central Alaska, while in southeastern Alaska, owing to the comparatively small size of the fish, it had waned and never recovered the importance it held in 1918, the pack exceeding 20,000 barrels only in 1922 when 30,000 barrels were packed. In central Alaska, however, over 100,000 barrels of herring were pickled in 1922 and again in 1925.

The growth of the third type of herring industry, that for bait, is correlated with the growth of the halibut fishery which it supplies. The halibut fishery commenced in 1888, the first fishing being done on the banks of Washington and British Columbia. The fishery gradually worked north. By 1912 or 1913 it had become an important Alaska industry. The catch of halibut of the whole coast now totals about 53,000,000 pounds. Herring is the bait used to the practical exclusion of everything else. Since the halibut fishermen prefer fresh bait, claiming that the halibut take it more readily than the frozen, the majority of the bait herring are kept alive in pounds and sold fresh as needed, the cold-storage plants serving to tide over the too frequent periods when fresh herring are not obtainable. In 1927 the halibut industry used over 8,000,000 pounds of herring bait from Alaska. Of this, 4,600,000 pounds represents frozen bait from southeastern Alaska. Of the 3,400,000 pounds of fresh bait used, 2,800,000 pounds were from southeastern Alaska and 600,000 pounds from central Alaska. The bait statistics, especially those for fresh bait, are very incomplete, but it is practically certain that the amount of bait consumed has reached over 8,000,000 pounds for several years preceding 1927.

Some dry-salting of herring in bulk for the oriental market has been done. In 1910, Capt. A. W. Thomas built a large saltery for this purpose in Ketchikan, and in 1911 over 3,000,000 pounds were salted. In 1912, more competitors entered the field and over 13,700,000 pounds were prepared, but in 1913, in spite of the increased effort, the production fell to 8,700,000 pounds, and in 1914 most of the operators went out of business. Since that time, 1918 is the only year in which the dry-salted product in southeastern Alaska has exceeded 1,000,000 pounds. In recent years herring have been dry-salted in Cook Inlet to be sold to the domestic market for smoking, as much as 2,500,000 pounds being prepared in 1924.

During the early development of the Chatham Strait and Prince William Sound fisheries, the herring companies made a determined effort to establish a market for canned kippered herring. Commencing with nearly 20,000 cases in 1916, the output was increased until it reached over 100,000 cases in 1919, but all efforts to find a satisfactory market failed. In 1920, the last year, only 3,600 cases were canned. All of the product was canned in southeastern Alaska, with the exception of 34,000 cases canned in Prince William Sound in 1919.

A few minor industries may be mentioned. In 1904 the Juneau Packing Co. canned over 3,000 cases of herring at Juneau as one-quarter oil and three-quarters mustard sardines, but were unable to compete with those from the Atlantic coast. In 1926 a company on Chatham Strait installed a refrigeration unit and commenced shipping freshly kippered herring to the States. Another company followed suit in 1927. This development holds great promise for the future.

AREAS FISHED

The areas fished at different times by different phases of the industry have varied in accordance with such economic factors as labor and shipping facilities, and such biological factors as size, fatness, and quantity of herring available. In some

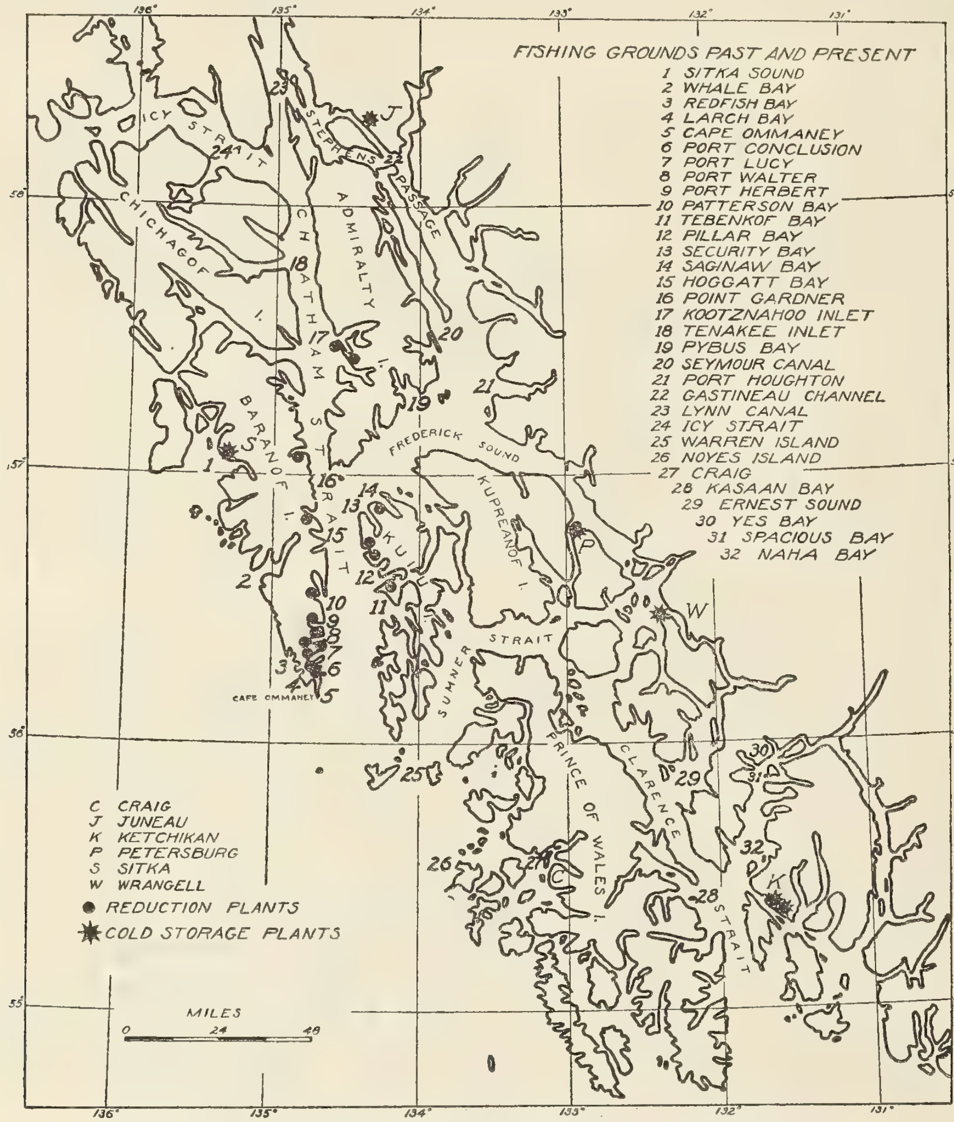

FIGURE 7.—Southeastern Alaska, showing the herring plants and the fishing grounds

localities herring appear only in the summer months, while in others they are taken only in the late fall or during spawning in the spring.

In southeastern Alaska (fig. 7) during the very early years of the fishery the one reduction plant at Killisnoo fished along Chatham Strait, especially in Kootznahoo Inlet (No. 17, fig. 7), and along the northern shore of Kuiu Island, while the other companies fished chiefly in the inside waters near Juneau and Petersburg—Pybus Bay, Seymour Canal, Port Houghton, Gastineau Channel, etc. (Nos. 19, 20, 21, and

22, fig. 7). From 1910 to 1914 an intensive fishery for herring to dry-salt for the oriental trade was carried on during the fall and winter months in Yes Bay and vicinity. (Nos. 30 and 31, fig. 7.) During these years the pickled-herring industry was gradually abandoning the waters near Petersburg and spreading toward Chatham Strait, which since 1916 has been the center of all phases of the industry, except the minor fishery for halibut bait. The bait fishermen continued to fish in the inside waters (which were close to the cold-storage plants), although with decreasing success, a large proportion of the bait used in the last few years being taken near the spawning grounds at Craig and in Sitka Sound. (Nos. 27 and 1, fig. 7.)

Information on the areas exploited by the summer herring fishery of southeastern Alaska, from 1922 to 1928, is contained in accurate records kept by a plant at Red Bluff Bay (on Baranof Island, in area 6, fig. 8). In compiling these records the fishing grounds have been divided into areas of approximately equal size. (Fig. 8.) Since the amount of gear used varied from year to year, only the percentage of the catch taken in each locality has been given. For 1927 and 1928 records are available for other plants and we have given the catches of two of these—from Big Port Walter in area 5W and from Killisnoo on Admiralty Island in area 10—so that the effect of the location of the plant on the areas fished might be observed. The table follows.

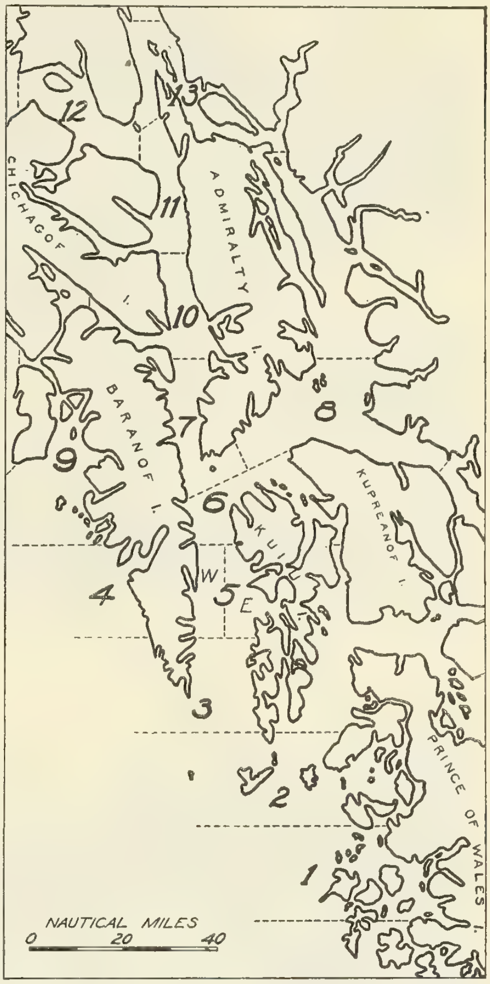

FIGURE 8.—Areas of southeastern Alaska by which the summer fishery has been analyzed in Table 1

TABLE 1.—*Per cent of catch taken in definite areas by certain plants in southeastern Alaska from 1922 to 1928, inclusive*

Area fished		Location of plants										
		Red Bluff Bay							Big Port Walter		Killisnoo	
No.	Designation	1922	1923	1924	1925	1926	1927	1928	1927	1928	1927	1928
1	Noyes Island							14.5	4.5	10.1		
2	Warren Island					0.6	2.1		1.9	.3		
3	Cape Ommaney	10.6	29.3	17.5	6.2	57.0	80.1	55.9	80.0	72.7	60.0	11.0
4	Whale Bay				.4	1.4	1.8		6.2	.3		
5W	Patterson Bay	29.5	6.8	2.6	42.4	8.4	1.4	.7		16.1		.4
5E	Tebenkof Bay	15.6	50.3	21.0	33.5	31.8	13.3	9.6	5.9	.2	2.5	
6	Security Bay	19.6	11.2	38.4	12.3	.5	1.6	.2			3.8	1.2
7	Point Gardner	24.9	.9	20.6	4.8	.2			.4	.2	25.0	.8
8	Pybus Bay				.3							1.0
9	Sitka Sound											10.6
10	Kootznahoo Inlet								1.1		5.4	7.9
11	Tenakee Inlet		1.5									.7
12	Icy Strait										3.3	13.8
13	Lynn Canal							19.2				52.6

The table shows several interesting facts. The amounts taken from areas 5, 6, and 7 (fig. 8) have decreased, and those from area 3 have increased. The amount taken from area 4 by the Red Bluff Bay plant was slight, but those plants located in area 3 obtained a large percentage of their 1925 catch from area 4. One of the most interesting and significant developments is the exploitation of distant areas, such as Noyes Island, Warren Island, Sitka Sound, Icy Strait, and Lynn Canal, in 1927 and

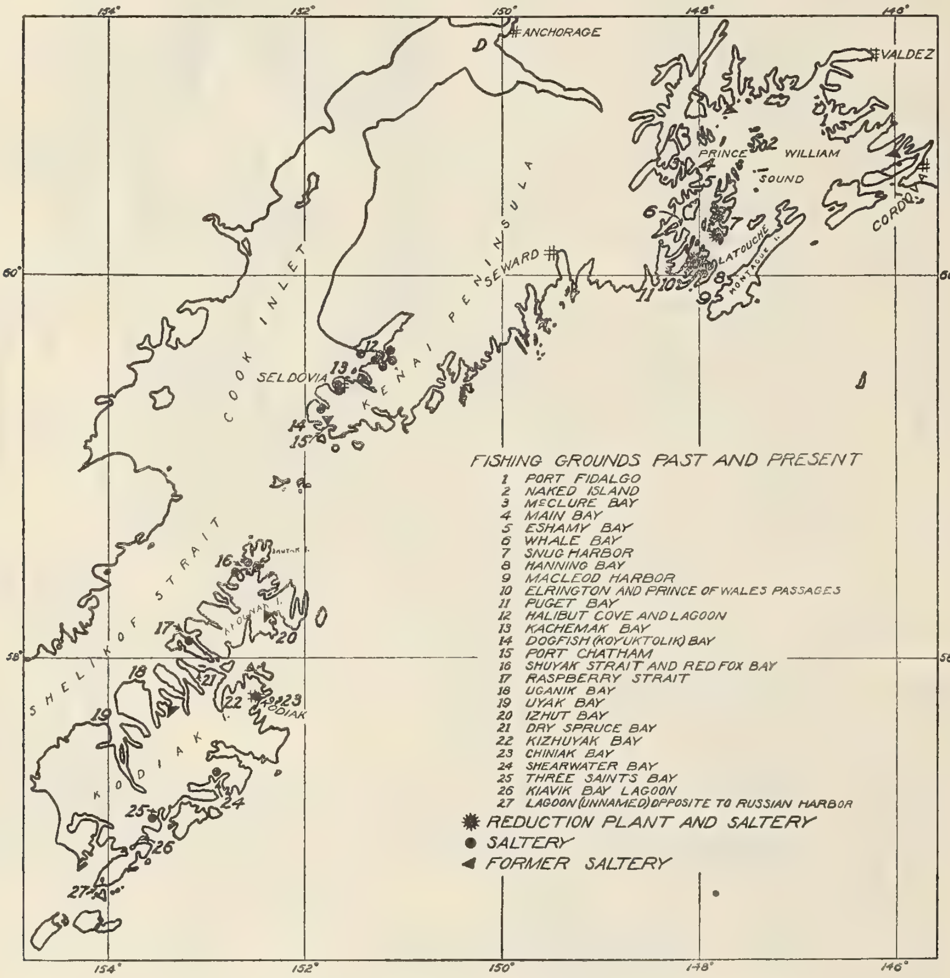

FIGURE 9.—Central Alaska, showing the herring plants and the fishing grounds

1928. This may indicate that a greater decrease in abundance has occurred than is shown by the catch analysis (to be discussed later, see fig. 47), the catch being maintained by shifting of the fishing grounds.

The central Alaska fishery is more recent. The western side of Prince William Sound has been subjected to intensive fishing since 1918. (Fig. 9.) In Cook Inlet gill-net fishing was commenced at Halibut Cove, Kachemak Bay, in 1914, and has continued up to the present, purse seining in Cook Inlet not commencing until 1923. On Kodiak Island fishing in a small way was being carried on in the vicinity of Kodiak by 1916, and Shearwater Bay has been exploited since 1921. On Afognak

FIGURE 10.—Small saltery erected at Unalaska in 1928. Herring were so plentiful that their pound, consisting of a small beach seine, is right alongside of the dock. The men in the foreground are obtaining herring from the pound for the day's operation

FIGURE 11.—The dock at Unalaska during the height of the herring run in August, 1928, showing the piles of empty barrels and the rows of packed barrels ready for shipment

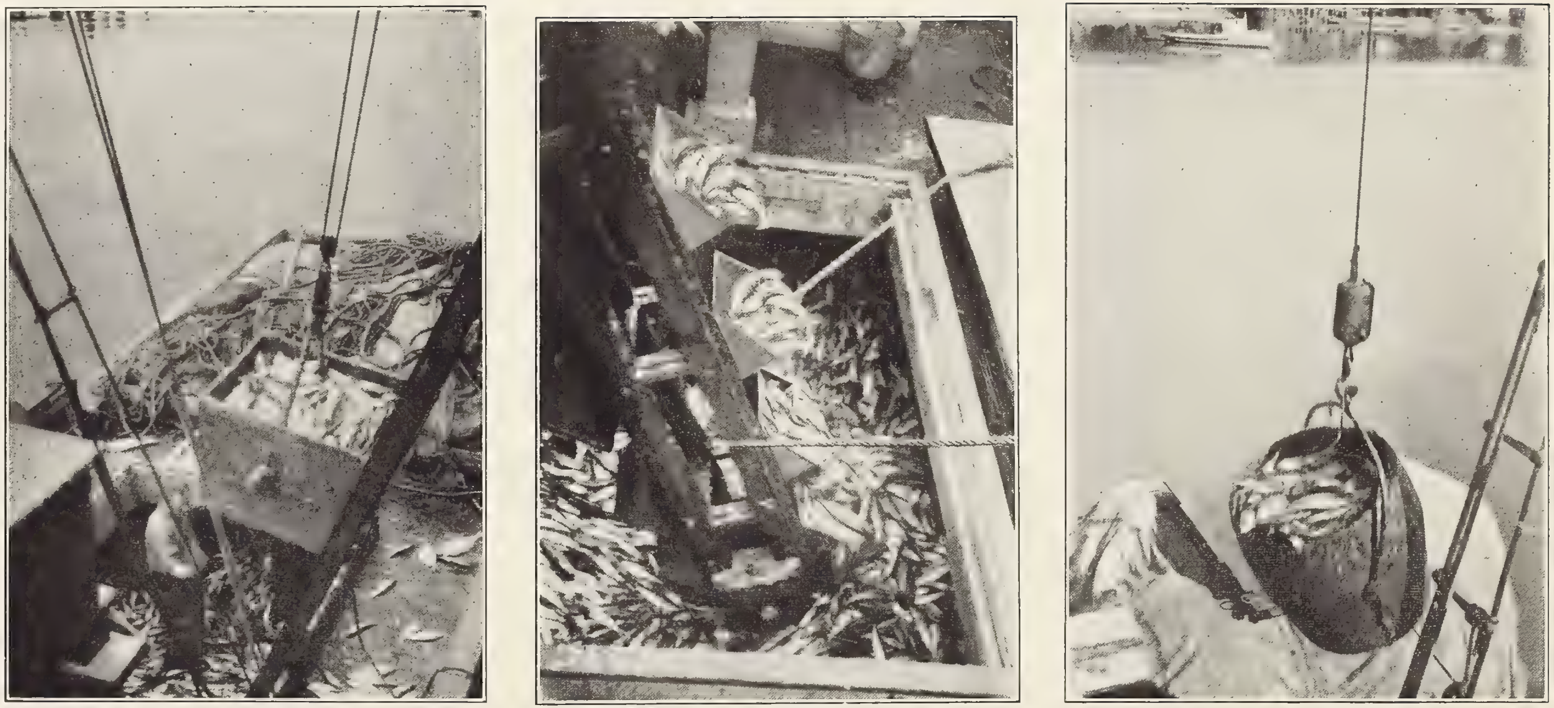

FIGURE 12.—Three methods of unloading herring from the seine boats

Island purse seining was first carried on in 1922 in Raspberry Strait and Izhut Bay. Since 1923 it has been largely confined to Shuyak Strait.

In western Alaska a very small gill-net fishery was established on Simeonof Island, one of the Shumagin group, in 1906. About the same time a small fishery was commenced near by at Chignik on the Alaska Peninsula. These two minor fisheries have continued up to the present. A small fishery has been carried on at Golovin Bay, in the northern part of the Bering Sea, since before 1909. However, no extensive fishery existed in western Alaska until 1928, when about half of the central Alaska purse-seine fleet fished at Unalaska (Dutch Harbor) in the Aleutian Islands. (Figs. 10 and 11.)

COLLECTION AND DESCRIPTION OF SAMPLES

SELECTION OF THE SAMPLE

In the collection of samples an effort was made to obtain a truly representative sample from each load. Care was taken not to select the sample in such a manner as to influence the size of the fish that were to be contained therein. The usual procedure was to hold a bucket under the fish elevator in such a manner that the fish dropped into it without any voluntary selection. (Fig. 12.) This was always done after the fishermen had shoveled off the top of the load since there is a tendency for the larger fish to rise to the top of the load and for the smaller fish to sink to the bottom. This tendency appears to act only upon the upper and lower few inches of the load, so that by taking samples from the middle of the load one does not incur the danger of under-representing the extreme sizes. In localities where the fish in the same load tend to cover a large range of sizes, samples of about 100 fish were usually taken. Where the range of sizes in the same load tended to be small, but the average sizes of fish of different loads varied considerably, then smaller samples of about 25 to 50 fish were taken, and an endeavor was made to sample more loads.

DATA TAKEN ON EACH SAMPLE

Having collected a random sample from a load of herring, the next step was to lay the herring in a row. Then a scale sample was taken from each fish from the middle of the side below the dorsal insertion. The scales were preserved in serially numbered coin envelopes and the corresponding number given each fish when its measurements were entered on the data sheet.

The fish were next measured, the measurements all being taken parallel to the body axis from a plane at right angles to the body axis at the tip of the mandible with the mouth closed. These were read in millimeters on an improved model of the fish-measuring board employed by Thompson (1917) in his investigation of the herring of British Columbia and later modified by Thompson (1926, p. 60), Elmer Higgins, and the author for taking sardine measurements at the California State Fisheries Laboratory (see fig. 13).

In making the measurements the wire on the cross arm of the measuring board was invariably aligned with its own reflection in the mirror. This always insured the eye being held vertically above the wire. As soon as each fish had been measured it was weighed on a spring balance graduated to 2 grams, with a capacity of 500 grams. After the measurements were all completed, the rays in the dorsal and anal fins were counted and the sex was then determined. The fish was reweighed with the entire

contents of the body cavity removed. With a sharp scalpel the flesh was cut from one side, exposing the vertebræ which were scraped clean and counted.

The complete list of data taken is as follows:

Measurements:
- From the tip of the closed mandible to—
  - The posterior end of the opercle, designated as the "head length."
  - The insertion of the dorsal fin.
  - The insertion of the anal fin.
  - Where the silvery epidermis of the body ends, more or less truncately, on the sides of the caudal peduncle, this measurement designated as "body length."
  - The ends of the caudal rays when the edges of the caudal fin are held parallel to the body axis, thus securing what is here called the "total length."

Counts:
- Vertebræ, excluding the hypural.
- Unbranched and branched dorsal rays.
- Unbranched and branched anal rays.

Weights:
- Total.
- With the entire contents of the body cavity removed, designated as the "cleaned weight."
- Gonads.

Other observations:
- The state of maturity of the gonads.
- Age, from sample of scales taken from the side under the insertion of the dorsal fin.

The head lengths and the distances to the insertions of the fins were expressed in all computations as percentages of the body length, these percentages being calculated with sufficient accuracy by means of a slide rule.

TABLES OF SAMPLES

The samples taken in this investigation from 1925 to 1928, inclusive, are presented in the following tables:

TABLE 2.—*1925 samples* [1]

Date	Number in sample [2]	Locality	Apparatus	Remarks
1925				
June 20	65	Clarence Straits, (Gravina Island)	Salmon trap	
26	100	Craig	Purse seine	Confined since April in pound, caught when spawning, thin and firm.
July 3	100	Whale Bay (Baranof Island)	do	
5	100	Tebenkof Bay (Chatham Strait)	do	
16	75	Point Gardner (Chatham Strait)	do	
17	35	do	do	
26	45	Elrington Passage	do	
27	45	Prince of Wales Passage (Elrington Passage)	do	
28	75	Shuyak Strait	do	Taken from boat in Evans Bay.
31	100	Procession Rocks (Elrington Passage)	do	
Aug. 3	50	Shuyak Strait	do	Do.
4	30	do	do	Do.
6	100	Dogfish Bay (Koyuktolik Bay)	do	Confined several days in a pound, very thin and firm.
7	75	Naked Island	do	
12	25	Shuyak Strait	do	
23	105	Lagoon on Kodiak Island opposite Russian Harbor.	Gill net of 3-inch mesh	

[1] All measured while fresh.

[2] Only one sample on each date.

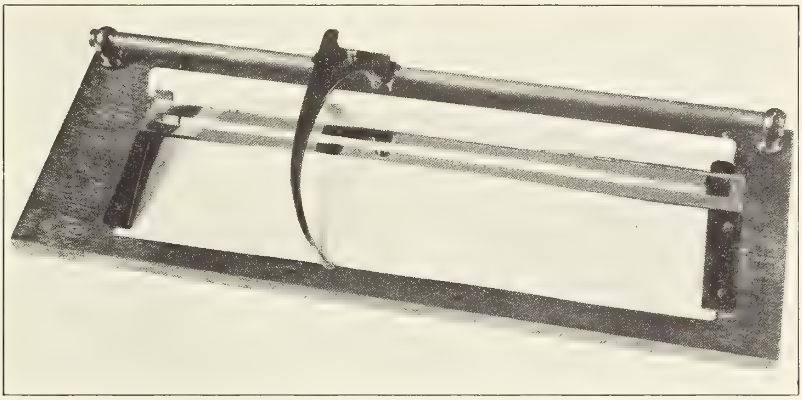

FIGURE 13.—Fish measuring board used in the herring investigation. Note the fine copper wire on the cross arm, and the mirror under the scale. The eye aligns the wire with its reflection in the mirror so that the eye is always held at right angles to the scale both in measuring and in reading

TABLE 3.—*1926 samples* [1]

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks
1926					
Apr. 12	1	161	Halibut Cove lagoon (Kachemak Bay)	Gill net of 3-inch mesh	
22	1	233	do	Beach seine, fine mesh	
27	1	47	Halibut Cove (Kachemak Bay)	do	
29	1	250	do	do	
29	1	41	do	Gill net of 3-inch mesh	
May 12	1	125	Behind McDonald Spit (Kachemak Bay).	Hands	Caught while spawning.
15	1	100	Homer Spit in lagoon (Kachemak Bay)	Dip net	Do.
18	1	10	Halibut Cove (Kachemak Bay)	Gill net of 3-inch mesh	
June 25	1	100	Elrington Passage	Purse seine	
26	4	200	do	do	
27	1	75	do	do	
28	1	100	do	do	
30	1	120	do	do	
30	1	75	Prince of Wales Passage (Elrington Passage).	do	
July 1	4	175	Cape Elrington (Elrington Passage)	do	
2	2	150	do	do	
8	1	50	Elrington Passage	do	
18	1	60	Red Fox Bay, Shuyak Strait	do	Impounded since July 15.
30	1	52	do	do	Do.
Aug. 5	1	22	do	do	
12	1	115	Old Harbor (near Three Saints' Bay)	Salmon trap	Thin spents.
19	1	100	Off McDonald Spit (Kachemak Bay)	Gill net of 3-inch mesh	
25	1	168	do	Purse seine	
27	1	100	Off McEwan Flats (Kachemak Bay)	do	
28	1	100	do	do	
29	1	100	do	do	
30	1	100	do	do	
Sept. 12	1	75	Off Falls Bay (Eshamy Bay)	do	
18	1	150	Eshamy Bay	do	
19	1	100	do	do	
20	1	150	do	do	
21	1	50	Off Glacier Spit (Kachemak Bay)	do	Taken from tender in Evans Bay, poor condition.
Oct. 25	1	324	Golovin Bay, Norton Sound	Beach seine	Full to throat.
Dec. 13	1	408	San Diego Bay	Gill net	Part very ripe, part of them developing, with small gonads.
Summer	1	456	Simeonof Bay (Shumagin Islands)	do	Recently spent, poorly preserved.
	1	107	Chignik Lagoon	Beach seine	Well preserved.

[1] All measured while fresh except the following: Golovin Bay, Simeonof Bay, and Chignik Lagoon, salted; San Diego Bay in formalin.

TABLE 4.—*1927 samples*

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks	Preservation
1927						
Feb. 3	1	25	Yakutat (wharf)	Dip net	All very small, immature	Formalin.
17	1	100	Puget Sound	(?)		Fresh.
Apr. 25	1	100	Halibut Cove (Kachemak Bay)	Beach seine		Do.
May 4	1	25	do	do		Do.
11	1	50	do	do		Do.
June 12	1	75	Naked Island	Purse seine	Impounded from May 29 to June 6. Pound covered with spawn. Very thin.	Do.
13	1	130	Macleod Harbor	do	Contain some belly fat	Do.
16	2	100	Prince of Wales Passage (Elrington Passage).	do		Do.
16	1	100	Naked Island	do	From same pound as June 12	Do.
17	1	50	Prince of Wales Passage (Elrington Passage).	do		Do.
21	1	100	do	do		Do.
25	1	100	Elrington Passage	do		Do.
25	1	45	Procession Rocks (Elrington Passage)	do		Do.
28	1	75	do	do		Do.
July 1	1	100	Macleod Harbor	do		Do.
2	1	50	Procession Rocks (Elrington Passage)	do		Do.
5	2	100	do	do		Do.
6	1	50	do	do		Do.
9	1	50	Macleod Harbor	do		Do.
13	1	285	Tebenkof Bay (Chatham Strait)	do	Small, poorly preserved	Formalin.
13	1	181	Larch Bay (Chatham Strait)	do	Poorly preserved	Do.
13	1	190	Point Gardner (Chatham Strait)	do	Preservation fair	Do.
14	1	168	Surprise Harbor (Point Gardner)	do	Well preserved	Do.
14	1	211	Shuyak Strait	do	Preservation fair	Do.
16	1	198	Outside north arm Pillar Bay (Chatham Strait).	do	Well preserved	Do.
19	1	199	Tebenkof Bay (Chatham Strait)	do	do	Do.

TABLE 4.—*1927 samples*—Continued

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks	Preservation
1927						
Aug. 3	1	201	Larch Bay (Chatham Strait)	Purse seine	Well preserved	Formalin.
5	1	97	do	do	Preservation fair	Do.
10	1	50	Off McDonald Spit (Kachemak Bay)	do		Fresh.
18	1	8	Belkofski Bay	Salmon trap		Formalin.
23	1	50	Off McDonald Spit (Kachemak Bay)	do		Fresh.
24	2	50	do	do		Do.
25	3	75	do	do		Do.
27	2	50	Off Yukon Island (Kachemak Bay)	do		Do.
Sept. 8	1	25	1 mile off between McDonald Spit and Barabara Point (Kachemak Bay).	do		Do.
21	1	50	Off Yukon Island (Kachemak Bay)	do		Do.
29	1	75	McClure Bay	do		Do.
30	3	100	do	do		Do.
Oct. 2	1	25	do	do		Do.
3	1	25	do	do		Do.
Dec. 17	1	52	Halibut Cove Light (Kachemak Bay)	Gill net, 3-inch mesh.	Well preserved	Formalin.
19	1	87	do	do	do	Do.
19	1	150	Halibut Cove Lagoon (Kachemak Bay)	do	do	Do.

TABLE 5.—*1928 samples* [1]

Date	Number of samples	Number in samples	Locality	Remarks [2]	Preservation
1928					
Jan. 27	1	975	¾ mile south of Eagle Harbor, Stephens Passage.	Good condition	Frozen.
Mar. 25	1	100	West coast Fish Egg Island (near Craig)	Good condition, taken while spawning	Do.
26	2	200	do	do	Do.
June 23	1	45	Elrington Passage	Fair condition	Fresh.
24	1	177	Puget Bay	Poor condition	Salted.
26	1	80	Macleod Harbor	Good condition	Fresh.
27	1	150	Snug Harbor, Knight Island	do	Do.
28	1	30	do	do	Do.
29	1	90	do	do	Do.
30	1	30	do	do	Do.
July 1	1	30	do	do	Do.
2	1	137	Port Fidalgo	do	Do.
5	1	60	Macleod Harbor	do	Do.
6	1	30	do	do	Do.
7	2	80	do	do	Do.
8	2	60	do	do	Do.
9	1	30	do	do	Do.
11	1	60	Bluff Point, Kachemak Bay	do	Do.
13	1	50	McDonald Spit, Kachemak Bay	Taken from boat in Shuyak Strait	Do.
30	1	90	Red Fox Bay, Shuyak Strait	Good condition	Do.
Aug. 9	1	50	do	do	Do.
20	1	40	Dutch Harbor, Unalaska Bay	Impounded 10 days	Do.
21	1	45	do	Good condition	Do.
27	1	60	do	Impounded Aug. 21	Frozen.
Sept. 9	1	100	Macleod Harbor	do	Fresh.
12	1	50	Dutch Harbor, Unalaska Bay	Good condition	Frozen.
12	1	50	do	Impounded Aug. 15	Do.
13	1	90	Macleod Harbor	Good condition	Fresh.
19	1	50	Dutch Harbor, Unalaska Bay	do	Frozen.
24	1	50	Macleod Harbor	Well preserved	Formalin.
25	1	50	do	do	Do.
Oct. 2	1	50	do	do	Do.
5	1	50	do	do	Do.
7	1	50	do	do	Do.
Autumn	1	165	Shearwater Bay	Preservation good	Salted.

[1] A sample of frozen fish from Sitka is on hand but not yet examined. [2] All samples caught with purse seine.

OTHER SAMPLES

In addition to the above data we were kindly given the length measurements of many samples of herring collected and measured to the quarter inch in total length by Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries, at Franklin Packing Co., Evans Bay. The 1924 samples contained 200 fish

each, the 1925 samples 100 fish each. The samples whose measurements are used in this report are as follows:

Date	Number	Locality	Date	Number	Locality
1924			1925		
July 17	1	Elrington Passage.	June 25	2	Elrington Passage.
18	1	Do.	26	4	Do.
18	1	Prince of Wales Passage (Elrington Passage).	27	2	Do.
19	1	Do.	July 10	2	Do.
21	1	Do.	11	2	Do.
24	1	Do.	12	1	Do.
25	1	Do.	12	2	Cape Elrington (Elrington Passage).
26	1	Do.	13	1	Do.
28	1	Do.	13	2	Elrington Passage.
29	1	Do.	14	2	Do.
			15	2	Do.
1925			16	1	Do.
June 22	2	Elrington Passage.	23	1	Do.
24	2	Do.	25	2	Do.

BIOLOGY OF THE PACIFIC HERRING

SYSTEMATIC RELATIONSHIPS

The family Clupeidæ contains many of the most important commercial fishes of the world. The herring occupies first place, followed by the menhaden, the sardines or pilchards, the shads, the alewives, the lake herrings, and many others of minor importance. The sardine or pilchard, Sardina, is perhaps the closest relative to the genus Clupea, which contains the herrings. Both genera contain Atlantic and Pacific species.

It is fitting that a survey be made of the degree of relationship existing between the Atlantic and Pacific herrings, *Clupea harengus* and *C. pallasii*, in order to justify the use in this investigation of some of the methods of research employed upon the Atlantic species. In Jordan and Evermann (1896, pp. 421–2), the European or Atlantic herring, *C. harengus* L., is described as having 18 dorsal rays, 17 anal rays, 57 scales on the lateral line, and 56 vertebræ; the Pacific herring, *C. pallasii* Cuv. and Val., as having 16 dorsal rays, 14 anal rays, 52 scales on the lateral line, and 50 vertebræ. When the Pacific form was described as a separate species, only specimens from the southern portion of the range were obtained, and, due to the fact that they differed widely from the Atlantic species in vertebral count, etc., the two were considered to be well defined. But we have had specimens of the Pacific form covering its range from San Diego Bay, near the Mexican border, to Golovin Bay in the northern part of the Bering Sea. Examination of these more representative samples shows that the differences between the two forms are not clear-cut, as one would infer from the taxonomic descriptions.

A summary of "racial" work on the European herring, by himself and other investigators, has been written by Johansen (1924). The total range of the vertebral count, excluding the hypural, in the North Sea and adjacent waters, is from 50 to 59 or a range of 10. For the Pacific herring (Table 6) the total range is from 45 to 57, or 13. The averages for the European herring (exclusive of the White Sea) vary from 53.78 for Zuider Zee herring (Delsman, 1914) to about 56.50 for Norwegian herring. Within the White Sea the averages of different "races" vary from 52.14 to 56.18 (Averinzev, 1926). For the Pacific herring the averages vary from 50.68 to 54.67. It is plain that the vertebral count is not a specific character in this case. In the White Sea herring the dorsal rays range from 16 to 22, with averages from 18.20 to 18.95; in the Pacific herring, from 15 to 21, with averages from 18.70 to 19.36. The anal rays range from 13 to 19, with means of 16.30 to 17.35 in the White Sea;

and range from 14 to 20, with means of 16.61 to 17.23 in the Pacific. Clearly neither the dorsal nor anal rays can be used as a specific character.

This leaves only a few minor characters with which to differentiate between individuals of the two species. However, Averinzev (1928) shows that the number of caudal and precaudal vertebræ and the number of keeled scales is practically the same between herring of the White Sea and a sample of Pacific herring from near Vladivostok. He believes the two species to be connected by forms extending across northern Siberia.

DISTRIBUTION AND SIZES

RANGE

The Pacific herring is found along both shores of the North Pacific, ranging from San Diego Bay on the south, north and west to the Aleutian Islands, and across to Japan and Siberia. They occur on both shores of Bering Sea, extending at least to Bering Strait. On this coast they occur in sufficient abundance in British Columbia and Alaska to support a considerable industry.

SIZE AND OCCURRENCE OF YOUNGER AGE GROUPS

In the herring, as in most pelagic fishes, the schools are not uniform as to the sizes and ages of the individuals contained therein. There is differential schooling, according to size, age, and sexual maturity. The degree and kind of segregation will vary at different seasons of the year, the schooling at spawning time depending chiefly on the state of maturity. The individuals in their first year are very small; those in Cook Inlet, from scale studies given later, are shown to be about 60 to 70 millimeters in body length when a year old. Fraser says (1916, p. 107) concerning the herring in the Straits of Georgia, "After a couple of weeks there is a gap until the fish is about 6½ months old on October 9. By this time the average length is about 5.2 centimeters and the weight 1.5 grams. The scales are already well started. On February 16 they have reached a length of 6.3 centimeters; April 4, 6.5 to 7.0 centimeters; and on May 16 (14 months), 7.6 centimeters." Thompson (1916, p. S48) gives the length frequencies of three samples of young herring taken in British Columbia in October, 1916, the samples varying from 6.7 to 7.7 centimeters in average length.

Very little is known as to the distribution of herring of this size, except that they can often be seen in immense numbers, never far from shore. We obtained a sample in Halibut Cove Lagoon with a fine-meshed beach seine, and Will F. Thompson obtained a sample at Yakutat by means of a light and a lift net.

During the summer of their second year the herring are about 120 to 140 millimeters in body length. In many of the inlets herring of this size are extremely numerous, and during the summer months the surface of the water close inshore often appears as though sprinkled with fine rain when they are feeding at the surface. Herring of this size are only occasionally taken with the larger sizes. The fishermen rarely deliberately make a catch of this size alone as they gill in the seines causing a great deal of extra work.

OCCURRENCE OF MATURE HERRING

The mature herring must approach the shore at least once each year in order to spawn. After spawning, the spent herring may disappear for a time. Whether they go into deeper water or are merely widely scattered is uncertain. In a few localities, as San Diego and San Francisco Bays, this spawning period is the only time at which the herring are observed and taken. In Alaska they spawn in late spring and then

may disappear for a time. They reappear in early summer and are found feeding close to the surface. Thus, schools of fattening herring, actively feeding, appear in late May in Chatham Strait and in early June in those western passages which lead into Prince William Sound. Schools of fat herring are caught in various parts of Chatham Strait until August, after which the bulk of the herring taken are caught off Cape Ommaney at the mouth of the strait, in September. In Prince William Sound the herring occur in the western passages in June and remain during part of July. In late September and October, schools of herring of larger and more uniform size occur in a few of the bays on the western shore of the sound.

In none of these cases does it seem possible, as yet, to trace a well-defined migration except perhaps between Shuyak Strait and Halibut Cove, Cook Inlet. Schools of large, fat, mature herring occur in Shuyak Strait in July and may remain during part of August. About six weeks after the appearance of the schools in Shuyak Strait, schools of large herring appear in lower Kachemak Bay. It is possible that these are the same schools. They gradually work farther up the bay until in September or October they appear off Halibut Cove. By this time the schools also contain fish of smaller sizes. Herring now enter Halibut Cove and the lagoon, where they are found until the following spring. Herring of all ages and sizes were found in the lagoon, apparently wintering there.

After the summer and fall fishery is over, herring occur during the winter months in some of the bays in southeastern Alaska where they do not usually occur in any quantity during the summer; for example, Ernest Sound, Stephens Passage, and Klawack Inlet, all of which are close to spawning grounds. But not enough is known to justify the view that these are regular migrations.

VARIATIONS IN SIZE OF MATURE HERRING

The variation in size of herring taken in different portions of their range plays a large part in determining their utilization, since for pickling purposes only large herring are desired. The herring are naturally smaller in some parts of their range than in others. This may be due to enormous differences in growth rate, as that between Unalaska and Stephens Passage, or largely to differences in age composition, as that between Prince William Sound and Cook Inlet.

N. B. Scofield (1918) says of the herring entering Tomales Bay, Calif., "They are considered the best herring in California and many of the fish reach a length of 10 or 11 inches and are fatter than those found in other parts of the State." He is evidently speaking of the total length. He says further, "The herring of Shelter Cove and Humboldt Bay are reported as being only 7 or 8 inches in length, * * *." The longest herring in Thompson's San Francisco Bay material (1916) was about 10 inches in total length.

Fraser (1922) mentions not finding any over 10 inches in length to the base of the caudal fin in British Columbia, and 10 inches to the base of the caudal was the longest recorded by Thompson (1917).

In southeastern Alaska herring of mixed sizes occur in the schools. The herring here may attain 12 inches in total length, but probably less than 10 per cent are over 10½ inches in total length.

The Prince William Sound herring are larger than those of southeastern Alaska. In the fall, some loads have as high as 75 per cent of the fish, by volume, over 10½ inches in total length, or about 9½ to 11 ounces in weight. Schools in this district are composed of herring of mixed sizes.

In Shuyak Strait the schools taken up to 1927 were made up almost entirely of large mature herring, many of them attaining a length of 14 inches. In 1928 only schools of small herring appeared. Herring of the same large size occur in Kachemak Bay in August, but a month later they are mixed somewhat with smaller sizes.

At Unalaska in 1928 the herring were very large, many of them being almost 15 inches. A very few persons have mentioned to the writer that they measured central Alaska herring that were 16 inches in length, but these were apparently exceedingly rare.

INDEPENDENCE OF AREAS

METHODS OF STUDY

Alarming changes in abundance have occurred in many localities. For instance, in Yes Bay and Kootznahoo Inlet in southeastern Alaska, herring were exceedingly abundant during the early years of the fishery, but soon became scarce and have remained so for many years. What caused the failure of such fisheries?

In studying these changes in abundance the first question raised is whether they are due to depletion or to variations in the migratory habits. Do the herring of the Alaska coast belong to one population that moves about at will, striking the coast wherever or whenever conditions impel it, or is each locality inhabited by a local stock that mingles but slightly, if at all, with the populations of adjacent areas? In the first case, fishing at any point on the coast would affect the supply at every other point, and if depletion occurred it would be general. In the second case, intensive fishing in one locality would not endanger the supply elsewhere, but the danger of local depletion would be highly intensified. The movement of the herring schools therefore becomes of great importance.

A study of these movements by the direct method of tagging the individual fish and obtaining records from the fishermen of the places of recapture has been successful in the cases of the plaice, cod, mackerel, salmon, halibut, and other fishes, but never in any of the clupeoid fishes. The ease with which impounded herring become infected with fungous growths, even when only a few scales have been lost, makes it appear probable that any wounds made in tagging might easily lead to death. Detection of the tagged individuals among the great numbers of the species taken at one time would be difficult enough without such heightened mortality. In the case of the Pacific herring it was felt that if attempted, tagging would never be successful except perhaps in a few localities. In southeastern Alaska and Prince William Sound, where the principal fisheries are conducted, a very large proportion of the herring are used for reduction purposes, and, since these fish are not handled individually, the chances of detecting a tagged fish, even if recaptured, are infinitely small. Because of these reasons, tagging was not seriously considered as a feasible means of studying migration in the herring and indirect methods were concentrated upon. However, owing to the concrete results to be attained by successful tagging we were unwilling to relinquish this method of investigation without giving it some trial.

Halibut Cove, Kachemak Bay, was chosen as the most favorable location for a test. In this district practically the entire catch is pickled, insuring the detection of any recaptured fish, since in this method the fish are handled one by one. Accordingly in the spring of 1927, 3,071 herring of pickling size were tagged with No. 3 monel metal strap tags attached to the caudal peduncle, as in the salmon.[3] The results, however, were negative.

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[3] A full description of this type of tag, with illustrations, is given by Gilbert and Rich (1925). The No. 3 tag, used on the herring, weighs 0.5 gram, is 3.3 millimeters in width, and about 14 millimeters in length when clinched.

The chance of success with a fish as small and delicate as the herring would seem to be very slight without the evolution of some special technique for handling the fish while tagging, and of some lighter and less cumbersome form of tag. It may well be that further experiments with such a tag would succeed.

Lacking successful direct methods, the widely used study of racial peculiarities becomes of primary importance. It is a well known fact that within the same species the isolation of particular stocks of fish tends to develop differences in their characteristics. These differences may exist in their physical structure or certain aspects of their life history, and may be too slight to detect in the individual but show in averages. They may be entirely the direct result of environment, or they may be inherited. But if two such stocks were to intermingle freely, so that half in each locality would have originated in the other, then any such differences would necessarily vanish, as the averages in each case would be the same. A difference which could originate as the result of different feeding conditions for a few months would not have the same significance as a difference which would require isolation for generations, and which might be deeply seated in heredity. Nevertheless, the existence of differences between any two localities is prima facie evidence of the more or less complete lack of intermingling, and the more deep seated and clear cut the difference, the less the rate of intermigration must have been. The relative importance of the parts played by heredity and environment in causing the constancy of these differences between populations is a moot question, but the important point at issue is not the cause of such differences, but rather their existence and extent.

Four of the structural characters were found to be of value—the counts of the vertebræ, of the dorsal rays, of the anal rays, and the measurements of the head length. The gill-raker count was taken on a number of samples, but it was found that accurate counts were not obtained under ordinary field conditions; and time in the laboratory was not available to make the enormous number of counts that would be required in order that their analysis might be of value. On a number of samples, measurements were made to the insertions of the dorsal and anal fins, but the variability was found to be so great that enormous numbers would have to be measured before any value could be attached to the results.

RACIAL SAMPLING

Samples were obtained from the southernmost limits of the herring's range, San Diego Bay, and from there in various regions west to the Aleutian Islands, and north to Golovin Bay in the northern part of the Bering Sea, an area covering 32 degrees of north latitude and 45 degrees of west longitude. Within this great area was obtained a fairly complete chain of samples. They were taken at San Diego Bay; Monterey Bay; San Francisco Bay; Puget Sound; southern British Columbia; southeastern Alaska; Yakutat; Prince William Sound; Cook Inlet; the Kodiak-Afognak district; from Chignik, the Shumagin Islands, and Belkofski Bay on the Alaska Peninsula, from Unalaska in the Aleutian Islands, and from Golovin Bay in the northern part of the Bering Sea. Unfortunately some of the samples, those from Yakutat and Belkofski Bay for example, are too small to give reliable averages for the characters.

Besides having samples from many localities, it is also important to have samples for more than one year from the same locality to study the amount of variability to be found in the same character at the same place. In this regard samples are present for 2 years from Kachemak Bay, 3 years from Prince William Sound, and 4 years from Shuyak Strait.

VERTEBRÆ

RELIABILITY OF VERTEBRAL COUNT

Of the four characters chosen to show structural differences, the vertebral count is the most reliable. The count is not altered by preservation and can be made with absolute accuracy and with greater ease than those of the fin rays. The number of vertebræ is determined at a very early stage, before or shortly after the hatching of the ova, so that it is not altered by any subsequent environmental conditions. Since the ova are attached, it is obvious that one adult population can not contribute, before the characters become fixed, to another adult population with different structural characters, as might be were the ova floating freely in the currents. On account of these advantages the differences in the vertebral count have received the chief emphasis in this analysis.

There are now available for comparison 10,132 vertebral counts of the Pacific herring. Of these counts, those from San Diego Bay, Puget Sound, and Alaska, totaling 7,960, are original. Those from Monterey Bay, the first two San Francisco Bay counts, and those from the Straits of Georgia are by Carl L. Hubbs (1925); the last San Francisco Bay count and the remainder of the British Columbia counts are by William F. Thompson (1916).

COMPARISON ALONG WHOLE LENGTH OF COAST

The average number of vertebræ increases to the northward and westward from San Diego. For the purpose of showing this, Table 6 and Figure 14 are presented. Table 6 gives the frequency distributions of vertebral counts in various localities and Figure 14 gives the means for each locality plotted against the distance from San Diego, following the general trend of the coast. The trend of the line of means has been drawn in by inspection.

TABLE 6.—*Variation in number of vertebræ in all samples of all localities*

No.	Locality	Vertebræ													Number	Mean	Probable error	Standard deviation of distribution
		45	46	47	48	49	50	51	52	53	54	55	56	57				
1	San Diego Bay					12	148	209	38	1					408	50.68	0.023	0.691
2	Monterey Bay					2	20	41	25	1					89	51.03	.06	
3	San Francisco Bay	1		1	4	18	256	410	125	5					820	50.78	.019	.797
4	Puget Sound				1		3	25	65	6					100	51.71	.052	.768
5	South British Columbia				1	1	28	354	738	138	3				1,263	51.78	.01	
6	Gravina Island							7	23	17	3				50	52.32	.075	.786
7	Craig						2	22	176	126	18				344	52.40	.026	.712
8	Larch Bay							13	173	239	36	2			463	52.66	.021	.681
9	Tebenkof Bay						2	20	228	381	50	1	1		683	52.68	.018	.683
10	Point Gardner							9	108	210	24	1			352	52.72	.023	.634
11	Whale Bay								6	15	4				25	52.92	.078	.580
12	Stephens Passage			1		3	3	86	459	368	40	2			962	52.33	.017	.769
13	Yakutat Bay						2		10	8	5				25	52.48	.163	1.205
14	Puget Bay							17	75	74	11				177	52.45	.038	.750
15	Elrington Passage						1	13	118	220	48	1			401	52.76	.024	.719
16	Macleod Harbor					1		14	116	192	42	2			367	52.72	.027	.755
17	Snug Harbor			1			1	16	139	143	22				322	52.55	.029	.772
18	Eshamy Bay							1	41	91	16	1			150	52.83	.035	.636
19	McClure Bay							5	45	143	30	1			224	52.90	.030	.657
20	Naked Island							3	41	75	19				138	52.80	.040	.693
21	Port Fidalgo						1	7	66	57	6				137	52.44	.040	.692
22	Dogfish Bay						1	9	34	51	5				100	52.50	.051	.763
23	Kachemak Bay				1	1		26	228	378	98	8			740	52.76	.031	.790
24	Shuyak Strait						1	20	180	261	66	3			531	52.72	.022	.757
25	Zachar Bay							2	21	52	12				87	52.85	.048	.670
26	Shearwater Bay							5	42	82	35	1			165	52.91	.041	.776
27	Old Harbor							1	30	63	17	3	1		115	52.95	.050	.790
28	Chignik							4	5	55	39	3	1		107	53.33	.053	.806
29	Shumagin Islands							1	7	36	130	213	62	7	456	54.67	.029	.928
30	Belkofski Bay								1	5	2				8	53.13		
31	Unalaska								20	106	54	3			183	53.22	.032	.650
32	Golovin Bay							2	43	77	18				140	52.79	.038	.671

It is obvious that the extreme variations shown in Figure 14 are significant, there being some underlying correlation between geographical distribution and number of vertebræ. The correlation is not an even one from south to north since the two localities farthest north, Golovin Bay and Eshamy Bay (Nos. 32 and 18, fig. 14) at

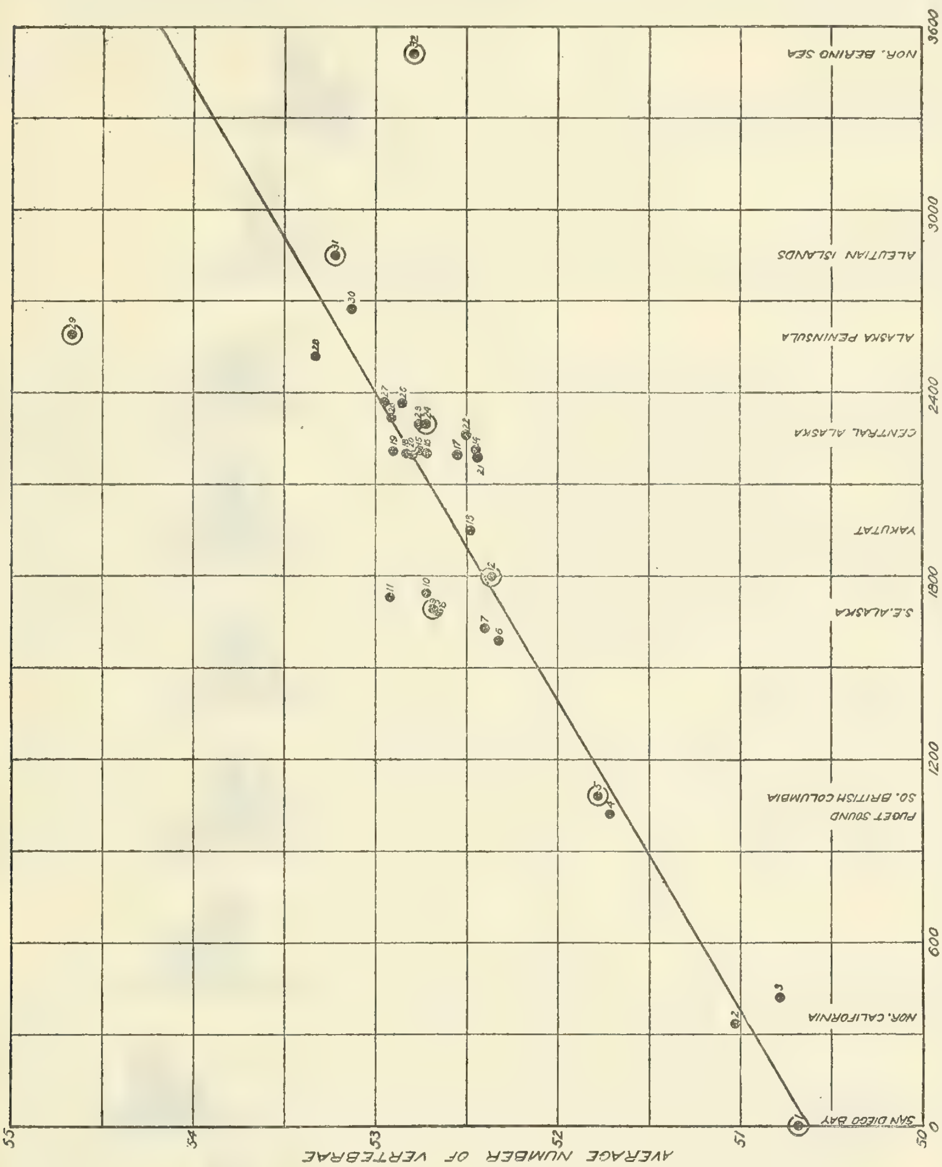

FIGURE 14.—Showing the increase in the average number of vertebræ following the general trend of the coast northward and westward from San Diego. Each locality numbered as in Table 6

64° 30′ and 60° 30 ′ north latitude, have means of only 52.79 and 52.83, while Chignik, the Shumagin Islands, and Unalaska, far to the south, have means of 53.33, 54.67, and 53.22, respectively. Except for the Shumagin Islands and Golovin Bay all of the localities follow the same trend. The existence of a more or less systematic change with geographical location indicates the reality of the differences aside from any consideration of adequacy of sampling.

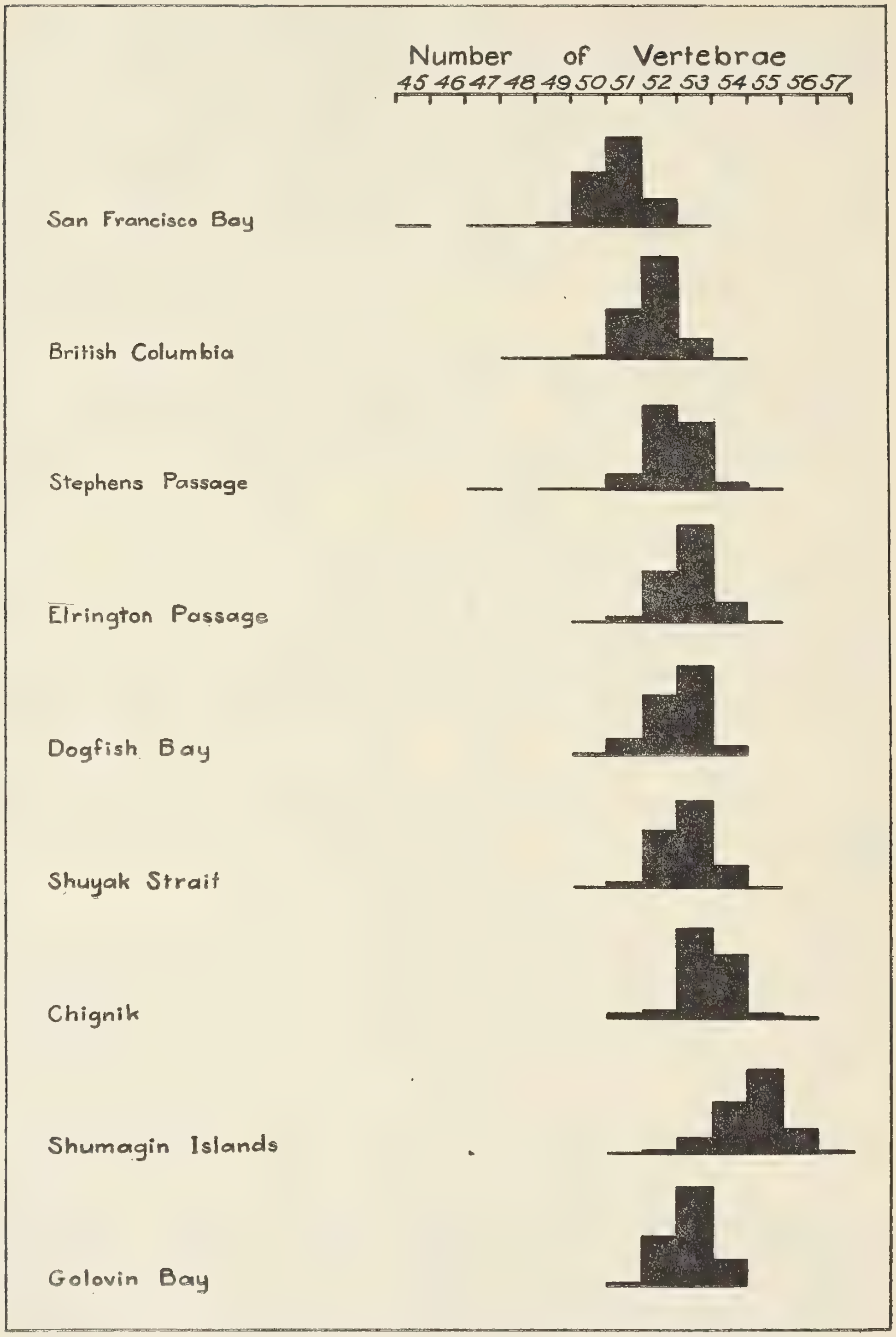

FIGURE 15.—Histograms showing the percentage of the vertebral distribution falling at each count

This method of comparison does not bring out the significance of differences as clearly from a mathematical standpoint as will the comparison of eight principal localities given in Table 7. (These eight localities are marked in fig. 14 by circles.) Here the averages for each locality are compared with those for the other localities, and their differences considered in relation to the probable errors of these differences, calculating the probable errors upon the assumption that the samples adequately represent the populations from which taken.

TABLE 7.—*Comparisons of the means of the vertebral counts of some distant localities*

[Asterisk shows differences that are not significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
San Diego Bay and South British Columbia	1.10	0.025	44.0	South British Columbia and Golovin Bay	1.01	0.039	25.9
San Diego Bay and Stephens Passage	1.28	.029	44.1	Stephens Passage and Tebenkof Bay	.32	.025	12.7
San Diego Bay and Tebenkof Bay	2.00	.029	69.0	Stephens Passage and Shuyak Strait	.36	.028	12.9
San Diego Bay and Shuyak Strait	2.04	.032	63.8	Stephens Passage and Shumagin Islands	2.31	.034	67.9
San Diego Bay and Shumagin Islands	3.99	.037	107.6	Stephens Passage and Unalaska	.86	.036	23.9
San Diego Bay and Unalaska	2.54	.039	65.2	Stephens Passage and Golovin Bay	.43	.042	10.2
San Diego Bay and Golovin Bay	2.11	.044	48.0	Tebenkof Bay and Shuyak Strait	.04	.028	* 1.4
South British Columbia and Stephens Passage	.58	.020	29.0	Tebenkof Bay and Shumagin Islands	1.99	.034	58.3
South British Columbia and Tebenkof Bay	.90	.020	45.0	Tebenkof Bay and Unalaska	.54	.037	14.6
South British Columbia and Shuyak Strait	.94	.024	39.2	Tebenkof Bay and Golovin Bay	.11	.042	* 2.6
South British Columbia and Shumagin Islands	2.89	.031	93.2	Shuyak Strait and Shumagin Islands	1.95	.036	54.2
South British Columbia and Unalaska	1.44	.033	43.6	Shuyak Strait and Unalaska	.50	.039	12.8
				Shuyak Strait and Golovin Bay	.07	.044	* 1.8
				Shumagin Islands and Unalaska	1.45	.043	33.7
				Shumagin Islands and Golovin Bay	1.88	.048	39.2
				Unalaska and Golovin Bay	.43	.050	8.6

It will be observed that this method indicates that local stocks of herrings, which are not shown to be obviously different by the visual comparison used in Figure 14, are actually sharply distinct from a mathematical viewpoint. Thus the difference between the herring of Tebenkof Bay and of Stephens Passage is significant, the difference between the means being 0.32 ± 0.025 or 12.8 times the probable error.

COMPARISON OF STOCKS OF ADJACENT LOCALITIES

This method of comparison may be applied also to closely adjacent localities within the same region. Thus Tables 13, 14, and 15 give comparisons of the means of the vertebral counts for southeastern Alaska (localities 7-13 of Table 6), Prince William Sound (localities 14–21), and Cook Inlet-Kodiak district (localities 22–27). Tables 8, 9, 10, 11, and 12 present the frequency distributions of vertebral counts upon which these comparisons are made, each minor locality being given separately and contributing to the totals for the general regions as listed in Table 6.

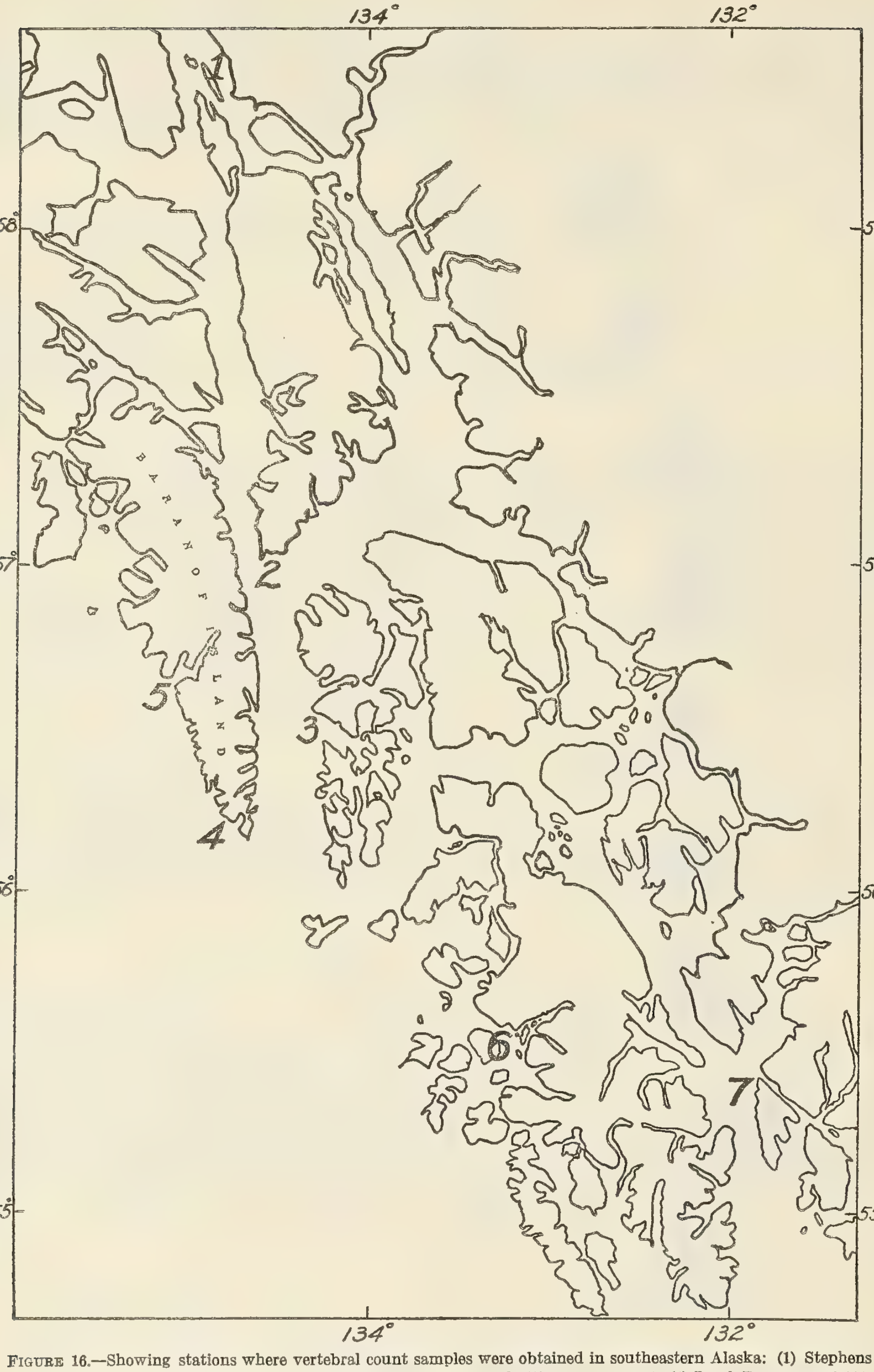

FIGURE 16.—Showing stations where vertebral count samples were obtained in southeastern Alaska: (1) Stephens Passage, 52.36±0.017; (2) Point Gardner, 52.72±0.023; (3) Tebenkof Bay, 52.68±0.018; (4) Larch Bay, 52.66±0.021; (5) Whale Bay, 52.92±0.078; (6) Craig, 52.40±0.026; and (7) Gravina Island, 52.32±0.075

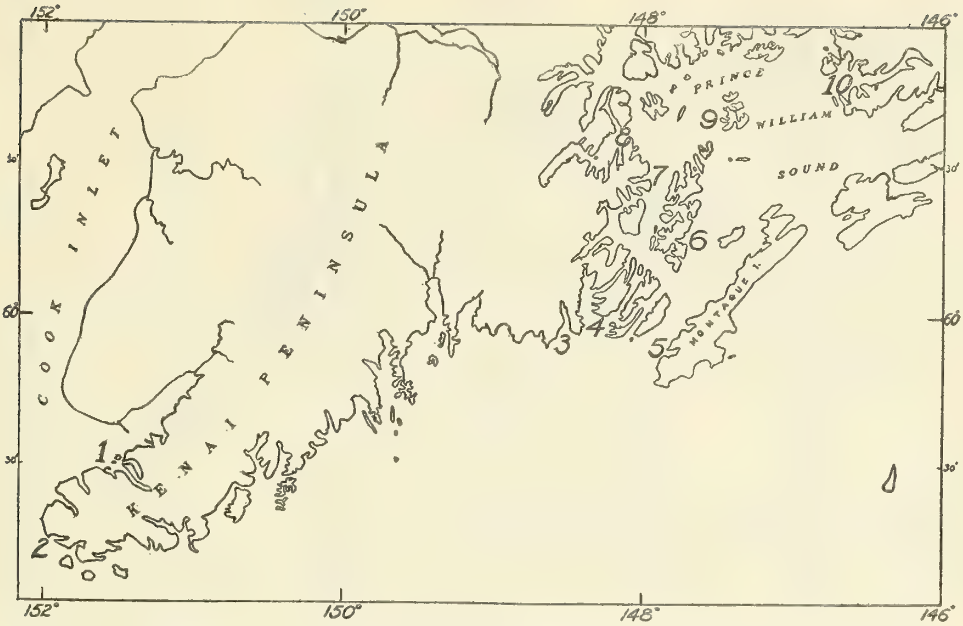

FIGURE 17.—Showing stations where vertebral count samples were obtained in Prince William Sound and Cook Inlet: (1) Kachemak Bay, 52.76±0.031; (2) Dogfish Bay, 52.50±0.051; (3) Puget Bay, 52.45±0.038; (4) Elrington Passage, 52.76±0.024; (5) Macleod Harbor, 52.72±0.027; (6) Snug Harbor, 52.55±0.029; (7) Eshamy Bay, 52.83±0.035; (8) McClure Bay, 52.90±0.030; (9) Naked Island, 52.80±0.040; and (10) Port Fidalgo, 52.44±0.040

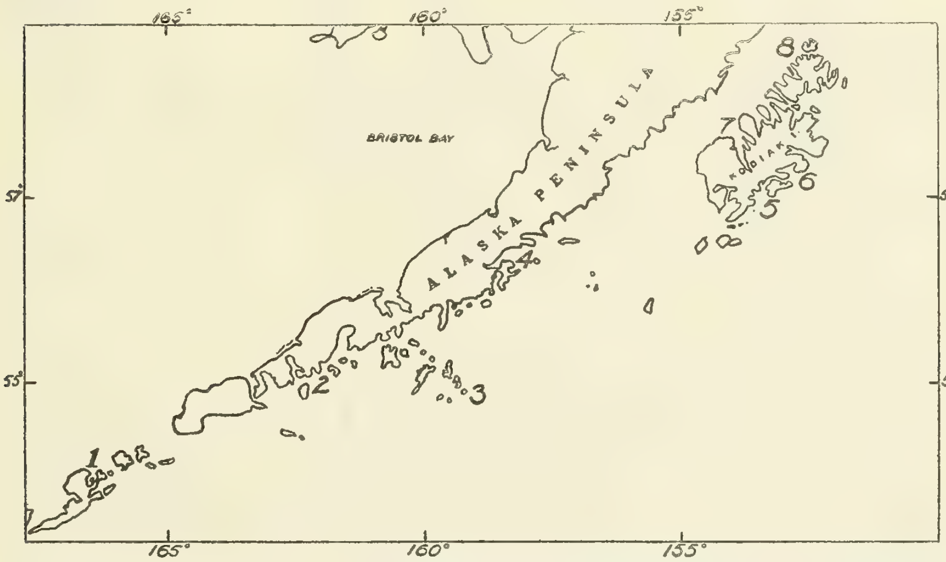

FIGURE 18.—Showing stations where vertebral count samples were obtained from Kodiak Island to Unalaska: (1) Unalaska (Dutch Harbor), 53.22±0.032; (2) Belkofski Bay, 53.13; (3) Shumagin Islands, 54.67±0.029; (4) Chignik, 53.33±0.053; (5) Old Harbor, 52.95±0.050; (6) Shearwater Bay, 52.91±0.041; (7) Zachar Bay, 52.85±0.048; and (8) Shuyak Strait, 52.72±0.022

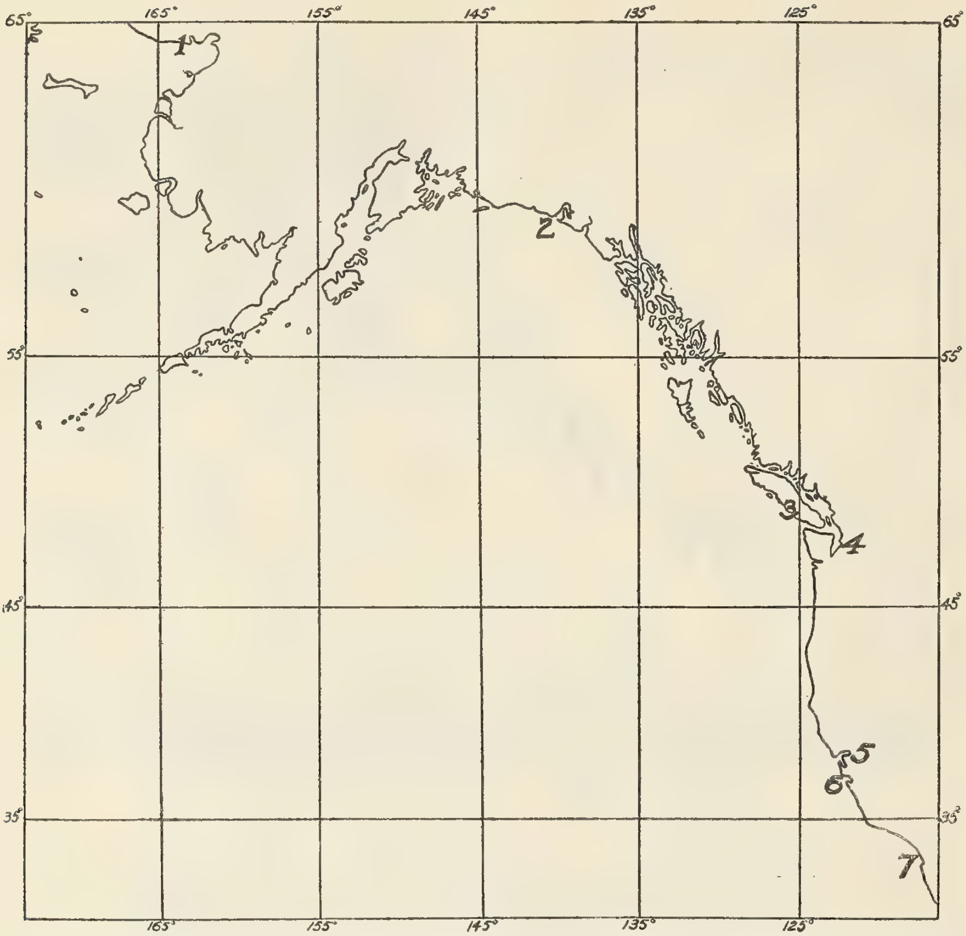

FIGURE 19.—Showing stations not on area maps where vertebral count samples were obtained: (1) Golovin Bay, 52.79±0.038; (2) Yakutat Bay, 52.48±0.163; (3) South British Columbia, 51.78±0.010; (4) Puget Sound, 51.71±0.052; (5) San Francisco Bay, 50.78±0.019; (6) Monterey Bay, 51.03±0.060; and (7) San Diego Bay, 50.68±0.023.

TABLE 8.—*Variation in number of vertebræ from California to British Columbia*

Locality	Date	Vertebræ										Number	Mean	Probable error	Standard deviation of distribution
		45	46	47	48	49	50	51	52	53	54				
San Diego Bay	1926					3	33	47	10	1		94	50.71	0.051	0.739
Monterey Bay	(?)					2	20	41	25	1		89	51.03	.06	
San Francisco Bay	1923			1	1	10	153	249	85	5		504	50.83	.02	
	1923					5	74	122	30			231	50.77	.03	
	1915	1			3	3	29	39	10			85	50.53	.08	
Total		1		1	4	18	256	410	125	5		820	50.78	.019	.797
Puget Sound	1927				1		3	25	65	6		100	51.71	.052	.768
British Columbia:															
Nanaimo	1915						4	51	136	19		210	51.81	.03	
Point Grey	1915						5	50	88	19	1	163	51.76	.04	
Straits of Georgia	1915						1	33	62	12		108	51.79	.04	
	1915				1		1	35	53	10		100	51.69	.05	
Pender Harbor	1915					1	7	89	150	32	2	281	51.75	.03	
	1915						2	23	60	11		96	51.83	.04	
Kildonan	1915						8	73	189	35		305	51.82	.02	
Total					1	1	28	354	738	138	3	1,263	51.78	.01	

TABLE 9.—*Variation in number of vertebræ in southeastern Alaska*

Locality	Date	Vertebræ										Number	Mean	Probable error	Standard deviation of distribution
		47	48	49	50	51	52	53	54	55	56				
Gravina Island	1925					7	23	17	3			50	52.32	0.075	0.786
Craig	1925				1	5	25	17	2			50	52.28	.074	.776
	1928					5	51	37	6			99	52.44	.046	.685
	1928					5	52	34	6			97	52.42	.047	.686
	1928				1	7	48	38	4			98	52.38	.049	.722
Total					2	22	176	126	18			344	52.40	.026	.712
Stephens Passage	1928	1		3	3	86	459	368	40	2		962	52.36	.017	.769
Tebenkof Bay	1925					1	10	13	1			25	52.56	.086	.638
	1927				2	12	94	153	12		1	274	52.60	.029	.709
	1927						61	113	18			192	52.78	.029	.601
North arm of Pillar Bay	1927					7	63	102	19	1		192	52.71	.035	.713
Total					2	20	228	381	50	1	1	683	52.68	.018	.683
Point Gardner	1927					3	62	111	12			188	52.70	.021	.608
Surprise Harbor	1927					6	46	99	12	1		164	52.73	.035	.671
Total						9	108	210	24	1		352	52.72	.023	.634
Larch Bay	1927					1	28	59	5			93	52.73	.040	.571
	1927					8	80	73	7	2		170	52.50	.037	.705
	1927					4	65	107	24			200	52.76	.033	.682
Total						13	173	239	36	2		463	52.66	.021	.681
Whale Bay	1925						6	15	4			25	52.92	.078	.680

TABLE 10.—*Variation in number of vertebræ in Prince William Sound*

Locality	Date	Vertebræ									Number	Mean	Probable error	Standard deviation of distribution
		47	48	49	50	51	52	53	54	55				
Elrington Passage	1925						10	29	6		45	52.91	0.053	0.526
Bainbridge Island	1925				1	4	33	46	16		100	52.72	.055	.814
Prince of Wales Pass	1925					2	14	22	6		44	52.73	.076	.750
Elrington Passage	1926					4	21	41	8	1	75	52.75	.060	.768
	1926					1	11	34	4		50	52.82	.056	.590
Prince of Wales Pass	1927					2	12	29	5		48	52.77	.064	.684
Procession Rocks	1927						17	19	3		39	52.64	.068	.628
Total					1	13	118	220	48	1	401	52.76	.024	.719
Macleod Harbor	1927					6	28	55	11		100	52.71	.050	.739
	1927					5	29	52	12	2	100	52.77	.054	.798
	1927					1	13	29	7		50	52.84	.064	.674
	1928			1			22	32	2		57	52.58	.065	.723
	1928					2	24	24	10		60	52.70	.068	.780
Total				1		14	116	192	42	2	367	52.72	.027	.755
Puget Bay	1928					17	75	74	11		177	52.45	.038	.750
Port Fidalgo	1928				1	7	66	57	6		137	52.44	.040	.692
Snug Harbor	1928					9	66	65	10		150	52.51	.039	.708
	1928					2	11	11	2		26	52.50	.089	.746
	1928				1		42	38	7		88	52.57	.057	.892
	1928	1				2	8	16	2		29	52.45	.195	1.557
	1928					3	12	13	1		29	52.41	.090	.720
Total		1			1	16	139	143	22		322	52.55	.029	.772
Eshamy Bay	1926						29	59	11	1	100	52.84	.044	.644
	1926					1	12	32	5		50	52.82	.060	.623
Total						1	41	91	16	1	150	52.83	.035	.636
Cabin Bay, Naked Island	1925					1	21	44	9		75	52.81	.050	.647
South Bay, Naked Island	1927						6	6	1		13	52.62		
	1927					2	14	25	9		50	52.82	.073	.767
Total						3	41	75	19		138	52.80	.040	.693
McClure Bay	1927					1	2	19	3		25	52.96	.081	.599
	1927					1	3	17	4		25	52.96	.089	.662
	1927						6	17	2		25	52.84	.073	.543
	1927					3	15	46	10		74	52.85	.062	.791
	1927						14	29	6	1	50	52.88	.065	.682
	1927						5	15	5		25	53.00	.085	.632
Total						5	45	143	30	1	224	52.90	.030	.657

TABLE 11.—*Variation in number of vertebræ in Cook Inlet and Kodiak-Afognak district*

Locality	Date	Vertebræ									Number	Mean	Probable error	Standard deviation of distribution
		48	49	50	51	52	53	54	55	56				
Kachemak Bay:														
Halibut Cove lagoon	1926	----	----	----	2	16	36	6	1	----	61	52.80	0.062	0.720
Homer Spit lagoon	1926	----	----	----	1	32	56	11	----	----	100	52.77	.044	.646
McEwan Flats	1926	----	----	----	4	21	29	9	1	----	64	52.72	.071	.838
McDonald Spit lagoon	1926	----	----	----	4	39	61	18	3	----	125	52.82	.049	.804
Off McDonald Spit	1926	----	----	----	2	29	35	10	----	----	76	52.70	.056	.726
	1926	----	----	----	4	36	44	15	1	----	100	52.73	.054	.798
McDonald Spit	1927	----	----	----	----	8	16	1	----	----	25	52.72	.091	.531
Halibut Cove Light	1927	----	----	----	4	25	42	14	2	----	87	52.82	.062	.857
Halibut Cove lagoon	1927	----	1	----	4	11	27	7	----	----	50	52.68	.092	.947
Halibut Cove Light	1927	1	----	----	1	11	32	7	----	----	52	52.79	.084	.927
Total	--------	1	1	----	26	228	378	98	8	----	740	52.76	.031	.790
Shuyak Strait	1925	----	----	----	1	27	38	9	----	----	75	52.73	.053	.680
	1925	----	----	----	3	14	26	7	----	----	50	52.74	.065	.770
	1925	----	----	----	----	14	13	3	----	----	30	52.63	.081	.650
	1926	----	----	----	1	8	11	4	1	----	25	52.84	.119	.880
	1926	----	----	----	1	7	15	2	----	----	25	52.72	.090	.666
	1926	----	----	----	5	14	23	9	1	----	52	52.75	.086	.920
	1927	----	----	1	3	71	106	27	1	----	209	52.76	.034	.728
	1928	----	----	----	2	12	13	2	----	----	29	52.52	.091	.724
	1928	----	----	----	4	13	16	3	----	----	36	52.50	.090	.799
Total	--------	----	----	1	20	180	261	66	3	----	531	52.72	.022	.757
Dogfish Bay	1925	----	----	1	9	34	51	5	----	----	100	52.50	.051	.763
Old Harbor	1926	----	----	----	1	30	63	17	3	1	115	52.95	.050	.790
Shearwater Bay	1928	----	----	----	5	42	82	35	1	----	165	52.91	.041	.776
Zachar Bay	1928	----	----	----	2	21	52	12	----	----	87	52.85	.048	.670

TABLE 12.—*Variation in number of vertebræ in western Alaska*

Locality	Date	Vertebræ							Number	Mean	Probable error	Standard deviation of distribution
		51	52	53	54	55	56	57				
Chignik	1926	4	5	55	39	3	1	----	107	53.33	0.053	0.806
Shumagin Islands	1926	1	7	36	130	213	62	7	456	54.67	.029	.928
Belkofski Bay	1927	----	1	5	2	----	----	----	8	53.13	--------	--------
Unalaska	1928	----	3	21	15	1	----	----	40	53.35	.067	.654
	1928	----	6	22	16	----	----	----	44	53.23	.068	.668
	1928	----	6	33	11	----	----	----	50	53.10	.055	.574
	1928	----	5	30	12	2	----	----	49	53.22	.065	.677
Total	--------	----	20	106	54	3	----	----	183	53.22	.032	.650
Golovin Bay	1926	2	43	77	18	----	----	----	140	52.79	.038	.671

In southeastern Alaska (Table 13) the three localities in Chatham Strait, Point Gardner, Tebenkof Bay, and Larch Bay show no differences which could be regarded as significant even were the samples truly representative. Both Craig and Stephens Passage show significant differences from these three Chatham Strait localities. Craig and Stephens Passage do not differ significantly from one another, but considering their geographical location, with the three Chatham Strait localities interposed, it may be supposed that they represent separate populations. In support of this contention, there are large spawning grounds, occupied at the same season of the year, both at Craig and in Stephens Passage. The samples from Gravina Island, Whale Bay, and Yakutat are only considered to be sufficient in numbers to give a general indication of the true mean.

TABLE 13.—*Comparisons of the means of the vertebral counts in southeastern Alaska*

[Asterisk shows differences that are probably significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
CHIEF LOCALITIES				MINOR LOCALITIES			
Craig and Stephens Passage	0.04	0.031	1.3	Gravina Island and Craig	0.08	0.079	1.1
Craig and Larch Bay	.26	.033	*7.9	Gravina Island and Larch Bay	.34	.078	*4.4
Craig and Tebenkof Bay	.28	.032	*8.7	Whale Bay and Craig	.52	.082	*6.3
Craig and Point Gardner	.32	.035	*9.1	Whale Bay and Larch Bay	.26	.081	3.2
Stephens Passage and Larch Bay	.30	.027	*11.1	Yakutat Bay and Craig	.08	.165	.5
Stephens Passage and Tebenkof Bay	.32	.025	*12.8	Yakutat Bay and Larch Bay	.18	.165	1.1
Stephens Passage and Point Gardner	.36	.029	*12.4				
Larch Bay and Tebenkof Bay	.02	.028	.7				
Larch Bay and Point Gardner	.06	.031	1.9				
Tebenkof Bay and Point Gardner	.04	.029	1.4				

In Prince William Sound (Table 14), the differences between the localities are not as great as in southeastern Alaska. It will be noted that there are three localities—Puget Bay, Snug Harbor, and Port Fidalgo—that do not differ significantly among themselves, but each of which differs from all of the other localities in Prince William Sound by an amount over four times its probable error, the significance of which will be discussed later. The only other differences of any possible significance occur between McClure Bay and Elrington Passage, and between McClure Bay and Macleod Harbor.

TABLE 14.—*Comparisons of the means of the vertebral counts in Prince William Sound*

[Asterisk shows those statistically significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Elrington Passage and Puget Bay	0.31	0.045	*6.9	Puget Bay and Port Fidalgo	0.01	0.055	0.2
Elrington Passage and Macleod Harbor	.04	.036	1.1	Macleod Harbor and Snug Harbor	.17	.040	*4.3
Elrington Passage and Snug Harbor	.21	.038	*5.5	Macleod Harbor and Eshamy Bay	.11	.045	2.4
Elrington Passage and Eshamy Bay	.07	.043	1.6	Macleod Harbor and McClure Bay	.18	.040	*4.5
Elrington Passage and McClure Bay	.14	.038	3.7	Macleod Harbor and Naked Island	.08	.048	1.7
Elrington Passage and Naked Island	.04	.047	.9	Macleod Harbor and Port Fidalgo	.28	.048	*5.8
Elrington Passage and Port Fidalgo	.32	.047	*6.8	Snug Harbor and Eshamy Bay	.28	.045	*6.2
Puget Bay and Macleod Harbor	.27	.047	*5.7	Snug Harbor and McClure Bay	.35	.042	*8.3
Puget Bay and Snug Harbor	.10	.057	1.8	Snug Harbor and Naked Island	.25	.049	*5.1
Puget Bay and Eshamy Bay	.38	.052	*7.3	Snug Harbor and Port Fidalgo	.11	.049	2.2
Puget Bay and McClure Bay	.45	.048	*9.4	Eshamy Bay and McClure Bay	.07	.046	1.5
Puget Bay and Naked Island	.35	.055	*6.4	Eshamy Bay and Naked Island	.03	.053	.6
				Eshamy Bay and Port Fidalgo	.39	.053	*7.4
				McClure Bay and Naked Island	.10	.050	2.0
				McClure Bay and Port Fidalgo	.46	.050	*9.2
				Naked Island and Port Fidalgo	.36	.057	*6.3

In the Cook Inlet and Kodiak-Afognak districts (Table 15) the extreme differences between localities are slightly less than in Prince William Sound, but there are several differences of probable statistical significance. Dogfish Bay differs from both Kachemak Bay and Shuyak Strait, the two nearest localities, by four

probable errors. Shuyak Strait differs from both Shearwater Bay and Old Harbor by four probable errors. All of the differences in these districts are of slight magnitude.

TABLE 15.—*Comparisons of the means of the vertebral counts in the Cook Inlet and Kodiak-Afognak districts*

[Asterisk shows those statistically significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Kachemak Bay and Dogfish Bay	0.26	0.060	*4.3	Dogfish Bay and Old Harbor	0.45	0.071	*6.3
Kachemak Bay and Shuyak Strait	.04	.038	1.0	Shuyak Strait and Zachar Bay	.13	.053	2.5
Kachemak Bay and Zachar Bay	.09	.057	1.6	Shuyak Strait and Shearwater Bay	.19	.046	*4.1
Kachemak Bay and Shearwater Bay	.15	.051	2.9	Shuyak Strait and Old Harbor	.23	.055	*4.2
Kachemak Bay and Old Harbor	.19	.059	3.2	Zachar Bay and Shearwater Bay	.06	.063	1.0
Dogfish Bay and Shuyak Strait	.22	.055	*4.0	Zachar Bay and Old Harbor	.10	.069	1.4
Dogfish Bay and Zachar Bay	.35	.070	*5.0	Shearwater Bay and Old Harbor	.04	.065	.6
Dogfish Bay and Shearwater Bay	.41	.065	*6.3				

In western Alaska (Table 7) the Shumagin Islands, Unalaska, and Golovin Bay have already been compared and the differences found to be large. The mean of the Chignik sample (Table 12) is lower than that of the Shumagin Islands, only 90 miles distant, by 1.34 ± 0.060 or 22 probable errors—a large difference from a mathematical standpoint.

VALIDITY OF DIFFERENCES IN VERTEBRAL COUNT

It is necessary to bear in mind that there are sources of variability other than those of pure chance, since the latter may not prevail in what we have regarded as random sampling. The actual significant variability which thus arises within each population must be determined empirically, since such internal variability could not be regarded as significant from the standpoint of the determination of the distinctness of populations. Without an understanding of the extent of these variations, one may be led into the fallacy of believing that any difference that is statistically significant denotes a racial difference, since the whole theory of probable errors presupposes that the samples compared represent adequately their respective populations. The variation which can be shown to actually arise *within* each stock furnishes a means of measuring the significance of differences between adjacent stocks. If the latter exceed the maximum internal difference, it is probably significant of isolation.

In Table 16 is given a comparison of different age classes from the same locality. The data are not extensive and the numbers involved are rather small, yet both Naked Island and McClure Bay show significant differences between the means of different year classes. The maximum significant difference found was 0.67 ± 0.113 or 5.9 times the probable error between two age classes of McClure Bay.

TABLE 16.—*Variation between the means of the vertebral count of different year classes from the same locality*

[Asterisk shows those statistically significant]

Locality	Year classes compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
McClure Bay	1920, 1921	0.19	0.073	2.6
	1920, 1922	.06	.082	.7
	1920, 1923	.48	.103	*4.7
	1921, 1922	.25	.095	2.6
	1921, 1923	.67	.113	*5.9
	1922, 1923	.42	.119	3.5
Eshamy Bay	1920, 1921	.09	.128	.7
Naked Island	1920, 1921	.50	.112	*4.5
Elrington Passage	1920, 1921	0.07	0.074	0.9
	1920, 1922	.07	.075	.9
	1920, 1923	.13	.071	1.8
	1921, 1922	.14	.084	1.7
	1921, 1923	.20	.081	2.5
	1922, 1923	.06	.081	.7
Macleod Harbor	1922, 1923	.36	.133	2.7
	1922, 1924	.25	.165	1.5
	1923, 1924	.11	.117	.9

This goes far toward explaining the variations to be found between samples from the same locality, as the mean of each sample will depend on the proportions of each year class present. As a rule, with samples of mature fish, one will have several year classes represented, so that means of successive samples will not fluctuate widely. However, in some cases, especially with schools of young fish, the sample may be composed very largely of fish of one year class. If this happens to be a year class that deviates widely from the average of the means of the year classes for that locality then the mean of the sample may differ considerably from the average for the locality.

Thus, in comparing two samples from the same locality one could expect to find a difference in means as great as 0.67 plus or minus its probable error (as in Table 16) if each of the samples contained fish of only one age, but of a different year class in each case. In comparing samples of fish from the same locality composed of several age groups such a large difference can not be expected, as the presence in the samples of fish spawned in several different years will cause the samples to show less variability than if composed of one age group.

Therefore, in evaluating the differences between any two localities, we must, if each sample is composed of one age group, have a difference of over 0.67 plus or minus its probable error before it approaches racial significance. This condition is seldom fulfilled, but, if not, we are confronted with another problem. Owing to changes in the proportions of each age group in different samples from the same locality there will be differences, aside from those due to chance, and the magnitude of these expected differences must be known so that they can be discounted in comparing samples from adjacent localities.

The magnitude of these expected differences for any two samples taken the same year in the same locality is shown by Table 17. These differences are not great, the average for the table being only 1.7 times its probable error. In Tebenkof Bay and Larch Bay the differences have statistical significance, being 4.4 and 5.2 times their probable errors, but in both of these cases the sample that varied most from the mean for the locality was composed largely of very small fish (between 120 and 150 millimeters), presumably largely of one age class. The effect this might have on the means has already been discussed. The actual difference between the means in Tebenkof Bay and in Larch Bay is 0.18 and 0.26, respectively. Elrington Passage and Unalaska have differences between samples of 0.19 and 0.25, respectively, which

approach statistical significance, and as in this case none of the samples were composed of fish of only one age class, one may conclude that in comparing samples from adjacent localities a difference of 0.25 plus or minus its probable error must be expected, and that any such difference should not, without further proof, be considered as due to the existence of distinct populations.

TABLE 17.—*Maximum variations between the means of the vertebral count of any two samples taken the same year in the same locality*

Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
San Francisco Bay	1923	0.06	0.036	1.7
Straits of Georgia	1915	.10	.064	1.6
Pender Harbor	1915	.08	.050	1.6
Craig	1928	.06	.071	.9
Tebenkof Bay	1927	.18	.041	[1] 4.4
Point Gardner	1927	.03	.041	.7
Larch Bay	1927	.26	.050	[1] 5.2
Elrington Passage	1925	.19	.076	[2] 2.5
	1926	.07	.082	.9
	1927	.13	.093	1.4
Macleod Harbor	1927	.13	.081	1.6
	1928	.12	.094	1.3
Snug Harbor	1928	.16	.106	1.5
Eshamy Bay	1926	.02	.074	.3
McClure Bay	1927	.16	.112	1.4
Kachemak Bay	1926	.12	.074	1.6
	1927	.14	.111	1.3
Shuyak Strait	1925	.11	.104	1.1
	1926	.12	.149	.8
	1928	.02	.128	.2
Unalaska	1928	.25	.087	[2] 2.9

[1] Statistically significant. [2] Approaching statistical significance.

But, aside from chance, the mean of any population will vary, not only between samples taken the same year, but between those taken in different years, owing to the changes in the proportions of the age classes and to the annual addition of a new year class. The magnitude of these variations is shown by Table 18. The average differences are 1.9 times their probable errors, only slightly higher than the difference between samples taken the same year. The largest difference found between any two samples is that of 0.30 ± 0.082 or 3.7 probable errors for San Francisco Bay. This difference, however, will not be applied to the present analysis for two reasons; first, because the two samples were counted by different investigators (1915 by Thompson, 1923 by Hubbs), and second, because the two samples were taken eight years apart, admitting of the possibility of this difference being caused by a long-time fluctuation that will not enter into our samples, none of which were taken over four years apart.

TABLE 18.—*Maximum variations between the means of the vertebral count of any two samples taken different years in the same locality*

[Asterisk indicates those approaching statistical significance]

Locality	Years compared	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
San Francisco Bay	1915, 1923	0.30	0.082	*3.7
Craig	1925, 1928	.16	.083	1.9
Tebenkof Bay	1925, 1927	.22	.091	*2.4
Elrington Passage	1925, 1926	.16	.080	2.0
	1925, 1927	.27	.088	*3.1
	1926, 1927	.18	.088	2.0
Macleod Harbor	1927, 1928	.26	.091	*2.9
Naked Island	1925, 1927	.01	.088	.1
Kachemak Bay	1926, 1927	0.11	0.104	0.1
Shuyak Strait	1925, 1926	.21	.144	1.5
	1925, 1927	.13	.087	1.5
	1925, 1928	.24	.111	*2.2
	1926, 1927	.08	.124	.6
	1926, 1928	.34	.149	*2.3
	1927, 1928	.26	.096	*2.7

Eliminating the San Francisco Bay samples, the maximum differences that approach statistical significance (between 2.7 and 3.1 times their probable errors) are those of Elrington Passage, Macleod Harbor, and Shuyak Strait, 0.27, 0.26, and 0.26, respectively. Although these differences are not of statistical significance, yet the fact that they appear in three localities attests to their validity. Hence in comparing samples from adjacent localities the significance of the differences must be open to question if they are smaller than 0.27.

Returning to the differences in vertebral count between distant localities (Table 7), it is apparent that they are very far in excess of any differences found between samples from the same locality, except in three cases (marked in Table 7 by an asterisk), in each of which the two populations compared were far apart and separated by others that are very distinct. This lack of difference is probably due entirely to accidental similarity.

In southeastern Alaska (Table 13), Craig and Stephens Passage (Nos. 7 and 12, Table 6 and fig. 14), both differ from the three Chatham Strait localities (Nos. 8, 9, and 10, Table 6 and fig. 14) by more than the maximum variability found between samples from one locality, 0.27 (Table 18), except in the case of Craig and Larch Bay, where the difference is only 0.26. In this case, however, the difference is 7.9 times its probable error, while the maximum difference found in the same locality (Table 18) is only 3.1 times its probable error, indicating that the difference between Craig and Larch Bay may be valid. Craig and Stephens Passage do not vary significantly between themselves, but their geographical position, with the distinct Chatham Strait stock between them, would indicate their independence.

In Prince William Sound (Table 14), as aforementioned, there are three localities—Puget Bay, Snug Harbor, and Port Fidalgo—that do not differ among themselves, but each of which shows a statistically significant difference with all of the other localities in Prince William Sound. In all three of these localities the range of sizes was small, varying chiefly from 150 to 190 millimeters, and so presumably the samples were composed very largely of 3-year-olds. As the fish in these samples were largely of one year class, the expected variability would presumably be analogous to that of the differences found between age classes of which the maximum was 0.67 ± 0.113, or 5.9 probable errors. The largest difference, that between Puget Bay and McClure Bay, is only 0.45 ± 0.048, or 9.4 probable errors so, although on the assumption that the sampling was truly random the difference is significant, we will not regard it as denoting a race because we know that the samples do not represent the same populations in age. McClure Bay differs from Elrington Passage by 0.14 ± 0.038, or 3.7 probable errors, and from Macleod Harbor by 0.18 ± 0.040, or 4.5 probable errors. Both of these differences are less than the 0.27 maximum variability between samples from the same locality, so they will not be considered as valid. Our data do not, therefore, demonstrate the existence of more than one stock of herring in Prince William Sound.

In the Cook Inlet and Kodiak-Afognak districts the maximum differences between localities are small. Dogfish Bay shows statistically significant differences between both Kachemak Bay and Shuyak Strait, but the actual differences, 0.26 and 0.22, are slightly less than 0.27—the maximum difference found between samples in one locality—hence Dogfish Bay can not safely be considered as racially distinct, especially as only one sample was obtained. Shuyak Strait differs from both Old Harbor and Shearwater Bay by four probable errors, the actual differences being

0.19 and 0.23, respectively. Although these actual differences are less than the maximum actual difference, 0.27, found between samples in the same locality, yet there is good reason for considering them to be valid. The Shuyak Strait mean is derived from nine samples taken over four years and representing a number of year classes, so that it should not be expected to vary as widely as the mean of a single sample. The Old Harbor and Shearwater Bay samples, from practically the same locality, containing 115 and 165 specimens, respectively, differ only by 0.04, although taken two years apart, in 1926 and 1928. This would attest to the reliability of their means. Hence we have provisionally considered Shuyak Strait and Old Harbor-Shearwater Bay to be racially distinct.

In western Alaska (Table 7) the Shumagin Islands, Unalaska, and Golovin Bay have already been shown to differ by amounts well in excess of any differences found in the same locality. The mean of the Chignik sample (Table 12) is lower than that of the Shumagin Islands, only 90 miles distant, by 1.34 ± 0.060, or 22 probable errors. This also is considerably in excess of any variations found in the same locality, so Chignik may be considered racially distinct.

SUMMARY OF VERTEBRAL COUNT FINDINGS

1. Following the general trend of the coast northward and westward from San Diego the means of the vertebral counts increase with the distance, the general trend being practically linear and widely departed from only by the herring of the Shumagin Islands and Golovin Bay.
2. Statistically significant differences are found between the vertebral count of different age classes from the same locality.
3. Successive samples from the same locality show differences larger than any assignable to chance.
4. In practically every case distant localities show differences greatly in excess of any that can be assigned to variations within the same population, as determined by the maximum variation between the means of samples from the same locality.
5. Many closely adjacent localities also show differences in excess of any assignable to variation in the same locality.
6. The analysis of the means of the vertebral counts indicates the distinctness of the populations in the following areas from the stocks of other areas sampled: California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Cook Inlet-Shuyak Strait-Prince William Sound, Shearwater Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay.

DORSAL RAYS

We have for comparison 3,864 dorsal-ray counts distributed from Puget Sound to Unalaska (Table 19). To avoid all errors in counting due to preservation, we have only used counts made on fresh specimens. Counts are available from other investigators but we do not care to use them in comparison with our own due to the chances for personal error in counting.

TABLE 19.—*Variation in number of dorsal rays*

Locality	Date	Number of rays							Number	Mean	Probable error	Standard deviation of distribution
		15	16	17	18	19	20	21				
Puget Sound	1927	----	----	1	34	54	3	----	98	18.73	0.043	0.627
Southeastern Alaska:												
Craig	1925	----	----	3	38	52	7	----	100	18.63	.045	.660
	1928	----	----	2	34	44	7	1	88	18.67	.055	.763
	1928	----	----	----	25	60	13	----	98	18.88	.042	.610
	1928	----	----	3	31	52	11	----	97	18.73	.048	.696
Total for Craig		----	----	8	128	208	38	1	383	18.73	.023	.673
Whale Bay	1925	1	----	1	38	54	4	1	99	18.62	.049	.723
Tebenkof Bay	1925	----	----	5	28	58	9	----	100	18.71	.047	.699
Point Gardner	1925	----	----	1	46	52	2	----	101	18.55	.037	.556
Stephens Passage	1928	----	1	9	249	562	128	6	955	18.86	.015	.670
Total for southeastern Alaska		1	1	24	489	934	181	8	1,638	18.79	.011	.676
Yakutat	1927	----	----	----	2	12	11	----	25	19.36	.082	.609
Prince William Sound:												
Elrington Passage	1925	----	----	----	10	28	7	----	45	18.93	.062	.613
Prince of Wales Passage	1925	----	----	2	12	26	5	----	45	18.76	.070	.706
Procession Rocks	1925	----	----	3	29	50	17	1	100	18.84	.052	.773
Elrington Passage	1925	----	----	----	13	32	5	----	50	18.84	.055	.580
Do	1925	----	----	1	34	30	10	----	75	18.65	.056	.724
Total for Elrington Passage		----	----	6	98	166	44	1	315	18.80	.027	.706
Macleod Harbor	1927	----	----	----	16	43	10	----	69	18.91	.049	.607
	1927	----	----	1	21	22	6	----	50	18.66	.068	.710
	1928	----	----	----	17	37	6	----	60	18.82	.051	.590
	1928	----	----	1	15	35	8	1	60	18.88	.061	.703
Total for Macleod Harbor		----	----	2	69	137	30	1	239	18.83	.029	.659
Snug Harbor	1928	----	----	1	12	27	10	----	50	18.92	.067	.716
Eshamy Bay	1926	----	----	2	33	74	16	----	125	18.83	.039	.654
McClure Bay	1927	----	----	2	19	45	8	----	74	18.80	.052	.657
	1927	----	----	----	5	17	3	----	25	18.92	.075	.559
Total for McClure Bay		----	----	2	24	62	11	----	99	18.83	.043	.636
Naked Island	1925	----	----	----	23	43	9	----	75	18.81	.049	.628
Port Fidalgo	1928	1	----	2	23	41	10	----	77	18.73	.063	.815
Total for Prince William Sound		1	----	15	282	550	130	2	980	18.81	.015	.686
Dogfish Bay	1925	----	----	1	15	65	16	3	100	19.05	.046	.684
Kachemak Bay:												
Halibut Cove lagoon	1926	----	----	1	12	31	6	----	50	18.84	.061	.644
Homer Spit lagoon	1926	----	----	3	34	51	12	----	100	18.72	.048	.710
McDonald Spit lagoon	1926	----	----	2	54	54	15	----	125	18.66	.043	.710
Off McDonald Spit	1926	----	1	3	36	50	15	----	105	18.71	.051	.779
	1926	----	----	3	37	54	6	----	100	18.63	.043	.643
	1927	----	----	----	6	15	3	----	24	18.87	.077	.599
Total for Kachemak Bay		----	1	12	179	255	57	----	504	18.70	.021	.702
Shuyak Strait	1925	----	----	3	25	36	11	----	75	18.73	.059	.755
	1925	----	----	3	12	27	6	2	50	18.84	.082	.860
	1925	----	----	----	8	17	5	----	30	18.90	.080	.650
	1926	----	----	1	24	23	2	----	50	18.52	.058	.609
	1926	----	----	----	7	14	1	----	22	18.73	.077	.539
Total for Shuyak Strait		----	----	7	76	117	25	2	227	18.72	.032	.718
Old Harbor	1926	----	----	2	41	51	15	----	109	18.73	.046	.715
Unalaska	1928	----	----	2	14	21	3	----	40	18.62	.074	.696
	1928	----	----	2	10	29	3	1	45	18.80	.072	.718
	1928	----	----	----	12	25	12	----	49	19.00	.067	.700
	1928	----	----	----	14	26	9	----	49	18.90	.065	.677
Total for Unalaska		----	----	4	50	101	27	1	183	18.84	.035	.710

Table 19 shows that the means of the dorsal-ray counts do not exhibit any general change throughout the range, as do the vertebræ, but appear to vary independently of geographical location. The nine principal localities are compared in Table 20. Out of 36 comparisons there are 16 that may be significant from a mathematical standpoint (see footnotes 1 and 2, Table 20). However, before considering these differences as valid we must know the amount of variability to be expected within any one locality.

TABLE 20.—*Comparisons of the means of the dorsal-ray counts of the principal localities*

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Puget Sound and Southeastern Alaska	0.06	0.045	1.3	Yakutat and Kachemak Bay	0.66	0.085	[1] 7.8
Puget Sound and Yakutat	.63	.093	[1] 6.8	Yakutat and Shuyak Strait	.64	.088	[1] 7.3
Puget Sound and Prince William Sound	.08	.046	1.7	Yakutat and Old Harbor	.63	.094	[1] 5.2
Puget Sound and Dogfish Bay	.32	.063	[2] 5.1	Yakutat and Unalaska	.52	.089	[1] 5.8
Puget Sound and Kachemak Bay	.03	.048	.6	Prince William Sound and Dogfish Bay	.24	.048	[2] 5.0
Puget Sound and Shuyak Strait	.01	.054	.2	Prince William Sound and Kachemak Bay	.11	.026	[2] 4.2
Puget Sound and Old Harbor	.00	.063	--------	Prince William Sound and Shuyak Strait	.09	.035	2.6
Puget Sound and Unalaska	.11	.056	2.0	Prince William Sound and Old Harbor	.08	.048	1.7
Southeastern Alaska and Yakutat	.57	.083	[1] 6.9	Prince William Sound and Unalaska	.03	.038	.8
Southeastern Alaska and Prince William Sound	.02	.019	1.1	Dogfish Bay and Kachemak Bay	.35	.050	[2] 7.0
Southeastern Alaska and Dogfish Bay	.26	.047	[2] 5.5	Dogfish Bay and Shuyak Strait	.33	.056	[2] 5.9
Southeastern Alaska and Kachemak Bay	.09	.024	[2] 3.8	Dogfish Bay and Old Harbor	.32	.065	[2] 4.9
Southeastern Alaska and Shuyak Strait	.07	.033	2.1	Dogfish Bay and Unalaska	.21	.057	[2] 3.7
Southeastern Alaska and Old Harbor	.06	.047	1.3	Kachemak Bay and Shuyak Strait	.02	.038	.5
Southeastern Alaska and Unalaska	.05	.036	1.4	Kachemak Bay and Old Harbor	.03	.050	.6
Yakutat and Prince William Sound	.55	.083	[1] 6.6	Kachemak Bay and Unalaska	.14	.040	3.5
Yakutat and Dogfish Bay	.31	.094	3.3	Shuyak Strait and Old Harbor	.01	.056	.2
				Shuyak Strait and Unalaska	.12	.047	2.6
				Old Harbor and Unalaska	.11	.057	1.9

[1] Of possible racial significance. [2] Of probable statistical significance.

The maximum differences between the means of any two samples taken the same year in the same locality are shown in Table 21. In three localities the differences between the means of the samples approach statistical significance (3.0 to 3.3 times the probable error) the maximum difference being 0.28 ± 0.084 or 3.3 probable errors. This would cast serious doubt on the significance of any difference not greater than 0.28, thus invalidating five of the differences in Table 20 that are valid from a mathematical standpoint.

TABLE 21.—*Maximum variations between the means of the dorsal-ray counts of any two samples taken the same year in the same locality*

[Asterisk indicates those approaching statistical significance]

Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference	Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
Craig	1928	0.21	0.069	*3.0	Kachemak Bay	1926	0.21	0.075	2.8
Elrington Passage	1925	.28	.084	*3.3	Shuyak Strait	1925	.17	.100	1.7
Macleod Harbor	1927	.25	.084	*3.0		1926	.21	.097	2.2
	1928	.06	.079	.8	Unalaska	1928	.28	.100	2.8
McClure Bay	1927	.12	.083	1.4					

The maximum variations found between the means of any two samples taken different years in the same locality are shown in Table 22. In two cases the differences are probably of statistical significance, being 0.25 ± 0.062 or 4.0 at Craig and 0.38 ± 0.099 or 3.8 probable errors for Shuyak Strait. As the maximum difference found between any two samples from the same locality, 0.38, is of probable statistical significance we can not claim as racial any lesser difference. This invalidates, from a racial standpoint, four more of the differences that are significant from a statistical standpoint (Table 20), leaving only seven differences that can be regarded as having possible racial significance.

TABLE 22.—*Maximum variations between the means of the dorsal-ray counts of any two samples taken different years in the same locality*

[Asterisk indicates those of probable statistical significance]

Locality	Years sampled	Difference between means	Probable error of difference	Difference divided by probable error of difference	Locality	Years sampled	Difference between means	Probable error of difference	Difference divided by probable error of difference
Craig	1925, 1928	0. 25	0. 062	*4. 0	Kachemak Bay	1926, 1927	0. 24	0. 088	2. 7
Macleod Harbor	1927, 1928	. 22	. 091	2. 4	Shuyak Strait	1925, 1926	. 38	. 099	*3. 8

Returning to Table 20, those differences that are statistically significant and exceed the maximum variability found between samples of the same locality are shown by footnote 1 reference. It is noted that all of these differences are between Yakutat and other localities, Yakutat differing significantly from all except Dogfish Bay. None of these differences are excessive, and we are inclined to doubt seriously their racial validity, for the Yakutat sample, besides being small in numbers, was composed entirely of very small fish (64 to 85 millimeters in length) which might introduce two sources of error, one being due to counting the rays of such exceedingly small fish in a different manner than those of larger specimens (a low power of the microscope was used), and another to the fact that they were all of one year class, which as we have seen in the case of the vertebral count, might easily account for large differences between the means.

In conclusion it may be said that the dorsal-ray count has not shown the distinctness of any populations.

ANAL RAYS

The anal-ray data contains 1,175 counts of fresh specimens (Table 23). In making the anal-ray count, doubt often arises owing to the diminutive size of the first, and often the second, unbranched ray. For this reason we have not compared our counts with those made by Thompson (1917) or Hubbs (1925), as there is no means of correctly evaluating any personal error that may have arisen as a result of this difficulty.

TABLE 23.—*Variation in number of anal rays*

Locality	Date	Number of rays							Number	Mean	Probable error	Standard deviation of distribution
		14	15	16	17	18	19	20				
Puget Sound	1927	----	5	40	37	11	1	----	94	16.61	0.056	0.808
Southeastern Alaska:												
Craig	1925	2	7	45	37	6	3	----	100	16.47	.061	.900
Whale Bay	1925	----	6	19	55	15	4	----	99	16.92	.056	.817
Tebenkof Bay	1925	----	5	22	40	23	9	----	99	17.09	.068	1.000
Point Gardner	1925	----	5	29	39	24	3	----	100	16.91	.062	.919
Total		2	23	115	171	68	19	----	398	16.85	.032	.950
Prince William Sound:												
Naked Island	1925	----	3	17	38	10	7	----	75	17.01	.074	.946
Deep Bay, Elrington Passage	1925	----	4	8	20	12	1	----	45	16.96	.095	.940
Prince of Wales Passage (Elrington Passage)	1925	----	2	10	15	15	3	----	45	17.16	.099	.990
Procession Rocks (Elrington Passage)	1925	----	1	16	45	28	9	1	100	17.31	.062	.915
McClure Bay	1927	1	1	11	30	24	7	----	74	17.30	.076	.967
Total		1	11	62	148	89	27	1	339	17.17	.035	.957
Dogfish Bay	1925	----	3	18	42	28	8	1	100	17.23	.065	.970
Halibut Cove	1926	----	1	13	26	9	----	----	49	16.88	.069	.718
Shuyak Strait	1925	1	9	49	73	21	2	----	155	16.71	.046	.844
Unalaska	1928	----	1	13	18	8	----	----	40	16.82	.082	.770

The means of the anal-ray counts do not show the same tendency to change with the distance along the coast as is present in the vertebral counts, as shown by Table 24 which compares the means of the principal localities. There is as great a tendency for large differences between adjacent localities as between distant localities. Thus of the 11 differences that may have statistical significance, 4 are between adjacent localities, and of the 10 differences that probably have no significance 8 are between distant localities.

TABLE 24.—*Comparisons of the means of the anal ray counts of the principal localities*

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Puget Sound and southeastern Alaska	0.24	0.064	[1] 3.8
Puget Sound and Prince William Sound	.46	.066	[2] 7.0
Puget Sound and Dogfish Bay	.62	.086	[2] 7.2
Puget Sound and Halibut Cove	.27	.089	3.1
Puget Sound and Shuyak Strait	.10	.072	1.4
Puget Sound and Unalaska	.21	.099	2.1
Southeastern Alaska and Prince William Sound	.32	.047	[1] 6.8
Southeastern Alaska and Dogfish Bay	.38	.072	[2] 5.3
Southeastern Alaska and Halibut Cove	.03	.076	.4
Southeastern Alaska and Shuyak Strait	.14	.056	2.5
Southeastern Alaska and Unalaska	0.03	0.088	0.3
Prince William Sound and Dogfish Bay	.06	.074	.8
Prince William Sound and Halibut Cove	.29	.077	[1] 3.8
Prince William Sound and Shuyak Strait	.46	.058	[2] 7.9
Prince William Sound and Unalaska	.35	.089	[1] 3.9
Dogfish Bay and Halibut Cove	.35	.095	[1] 3.7
Dogfish Bay and Shuyak Strait	.52	.080	[2] 6.5
Dogfish Bay and Unalaska	.41	.105	[2] 3.9
Halibut Cove and Shuyak Strait	.17	.083	2.0
Halibut Cove and Unalaska	.06	.107	.6
Shuyak Strait and Unalaska	.11	.094	1.2

[1] Of probable statistical significance. [2] Possibly a valid racial difference.

In inquiring into the validity of these differences it may be noted that in Elrington Passage the means of two samples taken the same year differ by 0.35 ± 0.113, or 3.1 probable errors. The maximum variability between any two samples from the same locality may well be larger, but at least this provides some measure of the expected differences.

Using this measure of variability it is found that in only six cases is the difference between the means of two samples greater than the 0.35 maximum variability found between samples from the same locality. Dogfish Bay is found to differ significantly from Shuyak Strait, Unalaska, southeastern Alaska, and Puget Sound. It differs from Halibut Cove by 0.35, which, being exactly the same amount as the maximum variability found between samples from the same locality, can not be considered as a valid racial difference. Puget Sound differs significantly from Prince William Sound. Prince William Sound differs from Shuyak Strait by 0.46 ± 0.058, or 7.9 probable errors, which is somewhat in excess of the variability found within one locality.

To conclude, the anal-ray count does not show any general change associated with distance as is the case with the vertebral count. Differences between distant localities are shown in a few cases. Taking into consideration the variability within one locality, it suggests that Shuyak Strait is independent of either Dogfish Bay or Prince William Sound.

HEAD LENGTHS

The length of the head increases with the growth of the fish but does not increase as rapidly as the length of the body. For this reason only head lengths of fish of approximately the same body length are strictly comparable. This being the case the head lengths have been expressed as percentages of the body length. (Table 25.)

TABLE 25.—*Average per cent head is of body length at each centimeter*

Length in millimeters	Puget Sound		Craig		Stephens Passage		Southeastern Alaska, total		Elrington Passage, 1925		Elrington Passage, 1926		Elrington Passage, 1927	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average
60–69														
70–79														
80–89														
90–99														
100–109					1	25.7	1	25.7						
110–119					5	26.1	5	26.1					1	24.6
120–129					21	25.3	21	25.3						
130–139					22	25.3	22	25.3					6	24.6
140–149					20	24.6	20	24.6					8	23.9
150–159					25	23.9	25	23.9					3	23.3
160–169	1	24.1	3	24.4	65	23.7	68	23.7					1	23.2
170–179	7	23.8	23	23.8	129	23.6	152	23.6	5	23.0			8	22.6
180–189	29	23.3	60	23.7	205	23.5	265	23.5	13	22.6	4	22.2	17	22.3
190–199	34	23.0	68	23.4	204	23.4	272	23.4	11	21.9	5	22.1	22	22.1
200–209	24	22.7	54	23.2	118	23.3	172	23.2	21	21.8	12	21.8	9	21.7
210–219	4	22.9	43	23.0	61	23.1	104	23.0	28	21.5	24	21.3	6	21.5
220–229	1	22.7	31	22.8	64	22.8	95	22.8	31	21.5	35	21.3	16	21.6
230–239			15	22.8	24	22.8	39	22.8	24	21.1	25	21.0	22	21.2
240–249			1	22.6	2	23.0	3	22.8	13	21.4	11	21.0	18	21.1
250–259									15	21.3	3	21.8	2	21.3
260–269									21	21.3	2	21.1	4	21.4
270–279									7	20.5	3	21.3	3	21.8
280–289									1	21.3				
290–299														
300–309											1	19.7		
310–319														

TABLE 25.—*Average per cent head is of body length at each centimeter*—Continued

Length in millimeters	Macleod Harbor, 1927		Eshamy Bay, 1926		McClure Bay, 1927		Naked Island, 1925		Naked Island, 1927		Prince William Sound, total		Dogfish Bay	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Aver age	Number	Average	Number	Average
60–69														
70–79														
80–89														
90–99														
100–109	1	26.5									1	26.5		
110–119											1	24.6		
120–129	2	24.2							1	24.2	3	24.2		
130–139	1	23.0									7	24.4		
140–149											8	23.9		
150–159	1	23.3									4	23.3		
160–169	7	23.2							1	23.8	9	23.3		
170–179	16	22.6	1	24.1					1	24.2	31	22.8		
180–189	31	22.4	1	22.4	1	22.4	1	23.2	5	23.4	73	22.5		
190–199	66	22.1	4	22.6	3	22.4	4	22.9	13	22.7	128	22.2		
200–209	39	22.0	3	21.8	12	22.3	7	22.1	12	22.5	115	22.0		
210–219	15	21.5	15	21.7	7	22.2	19	21.8	5	22.8	119	21.6		
220–229	7	21.1	27	21.4	13	21.5	27	21.6	8	22.4	164	21.5	1	22.3
230–239	6	21.0	90	21.3	20	21.4	8	21.7	14	22.0	209	21.3	3	22.1
240–249	6	21.6	41	21.0	29	21.6	1	21.7	9	21.8	128	21.3	6	21.8
250–259	2	21.9	11	21.1	11	21.1	2	21.6	3	20.8	49	21.2	21	21.7
260–269			2	21.0	1	21.0	4	21.3	2	21.1	36	21.3	47	21.5
270–279			5	20.7	2	21.7	2	20.8	1	21.1	23	21.0	20	21.3
280–289					1	21.2					2	21.3	2	19.9
290–299														
300–309											1	19.7		
310–319														

Length in millimeters	Lower Kachemak Bay, 1926		Lower Kachemak Bay, 1927		Halibut Cove, 1926		Halibut Cove, 1927		Shuyak Strait		Shuyak Strait, Halibut Cove, Lower Kachemak Bay, total		Russian Harbor	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average
60–69					2	26.7					2	26.6		
70–79					20	26.4					20	26.4		
80–89					2	25.8					2	25.8		
90–99					1	26.6					1	26.6		
100–109					1	26.5					1	26.5		
110–119					8	24.9					8	24.9		
120–129	3	24.1			16	24.8					19	24.7		
130–139	1	24.4			8	24.2					9	24.2		
140–149	1	22.4			9	24.4					10	24.2		
150–159					9	23.9					9	23.9		
160–169	1	22.9			2	22.5					3	22.6		
170–179					6	22.8	3	23.5			9	23.0		
180–189	1	21.3			4	22.2	3	23.0			8	22.4		
190–199			1	21.7	5	22.1	1	23.0			7	22.2		
200–209	5	21.5	4	21.6	8	22.2	8	22.7			25	22.1		
210–219	7	21.3	19	21.1			8	22.2	1	20.6	35	21.4		
220–229	2	21.3	33	20.9	13	21.5	15	21.8	2	20.8	65	21.2		
230–239	11	20.6	27	20.8	13	20.9	13	21.7	10	21.0	74	21.0		
240–249	12	20.5	16	20.8	10	20.9	9	21.2	19	20.6	66	20.8	1	19.3
250–259	34	20.1	16	20.5	30	20.6	3	21.1	40	20.3	123	20.5	10	19.7
260–269	66	20.0	21	20.0	51	20.5	4	21.5	58	20.4	200	20.3	26	19.8
270–279	88	19.7	33	20.2	49	20.3	3	21.2	79	20.2	252	20.1	25	20.0
280–289	54	19.7	25	20.0	18	20.1	4	20.7	27	19.9	128	19.9	19	19.6
290–299	23	19.6	4	20.0	10	19.9	1	20.8	22	19.7	60	19.8	19	19.9
300–309	4	19.9	1	19.9	2	20.2			1	20.2	8	20.0	5	19.8
310–319	2	19.1							1	19.4	3	19.2		

In treating the data the percentages have been averaged for centimeter body-length catagories, not using any averages from a category having a frequency of less than five. For each centimeter body-length category, the average per cent head length was used to calculate the average actual head length for that category. A straight line was then fitted to each actual head-length body-length relation by the method of least squares. The points on this straight line were then converted into

percentages at each length and replotted. The resulting smoothed curves gave a fair fit, as illustrated by Figure 20, showing the average percentages in each centimeter category and the smoothed curves for Elrington Passage in 1927 and Stephens Passage in 1928.

The smoothed head-length curves are shown in Figures 21, 22, and 23. Figure 21 shows that Craig and Stephens Passage are very similar, but southeastern Alaska

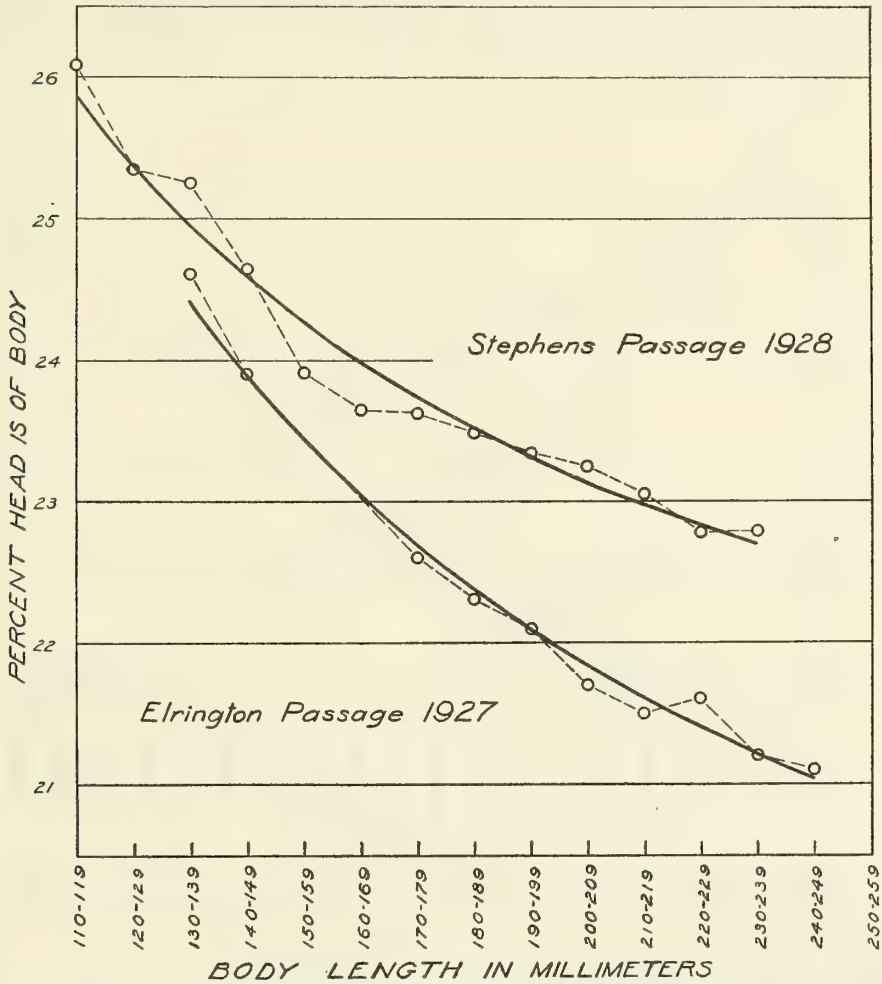

FIGURE 20.—Percentage head is of body. Smoothed curves and actual data for Elrington Passage, 1927, and Stephens Passage, 1928, to illustrate the closeness of fit of the smoothed curves

(the combination of the two curves) shows distinct differences from both Prince William Sound and the other central Alaska curve.

The component samples of the Prince William Sound curve are given in Figure 22. The McClure Bay and the two Naked Island samples are slightly above the main group but do not approach the southeastern Alaska group.

There is one disturbing factor in the comparisons of these head-length curves, and that is condition. The two Naked Island samples are a good illustration. The 1925 sample was taken in August when the fish were fat, while the 1927 Naked Island fish, with longer head measurements, were taken early in June and were extremely thin.

It would seem that when fat, fish might be expected to have a lesser head length than when thin, as the bulging of the sides of the fat fish, by increasing the angle between the opercle and the axis of the body, would tend to shorten the head-length measurement, which is taken to the posterior edge of the opercle.

Figure 23 gives the curves for the remainder of central Alaska. The dotted curve does not include the Dogfish Bay or Russian Harbor samples. All of the component curves, except that for Halibut Cove in 1927, fall in one group. Here again condition is a disturbing element. The 1927 Halibut Cove curve comes considerably

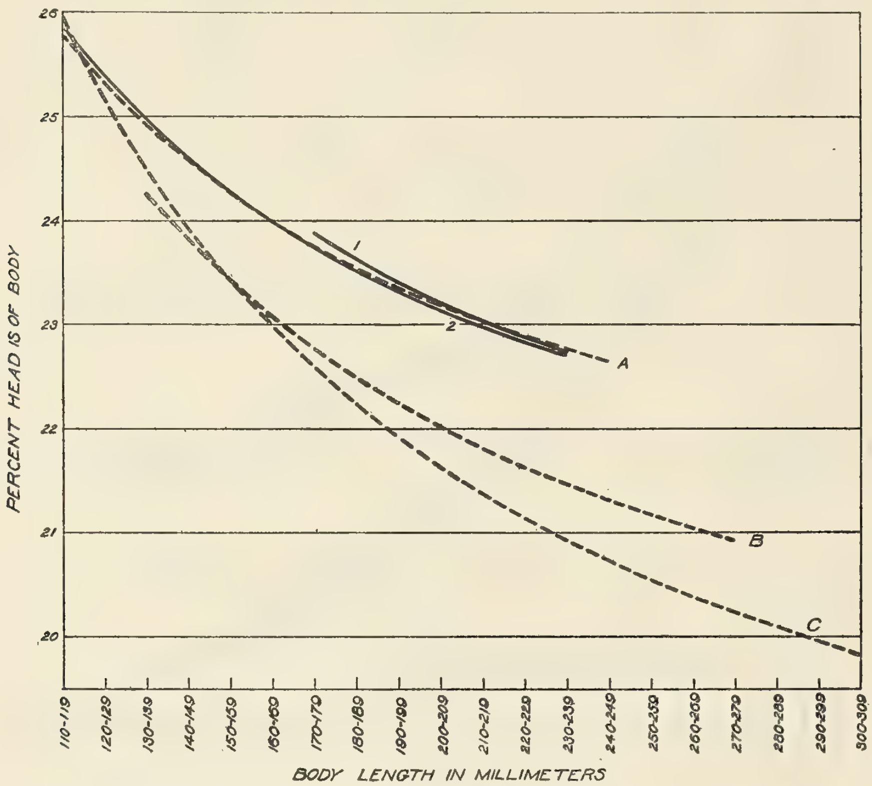

FIGURE 21.—Percentage head length is of body length. Showing: A, southeastern Alaska, (1) Craig; (2) Stephens Passage; B, Prince William Sound; and C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove

above that for 1926. Reference to the section on condition shows that the 1927 fish were much thinner than the 1926 fish.

The Dogfish Bay curve is 1 per cent higher than the combined curve for Shuyak Strait, Kachemak Bay, and Halibut Cove—a difference of 2.5 millimeters in fish of 250 millimeters in body length. The Dogfish Bay fish, although taken in August, were very thin, yet it seems improbable that such a difference could be entirely dependent on condition.

Certain conclusions may be drawn from the head-length analysis:

1. The head lengths in general decrease from the south toward the north and west, thus showing a change with distance, as do the vertebral counts.

2. While the differences between the curves can not be calculated mathematically owing to the differences in slope, the fact that the curves for the individual localities

from each main group do not overlap the curves for the other main groups, except in the cases of Dogfish Bay and Halibut Cove, 1927 (which, as mentioned before, may be due to condition), is sufficient proof of the real significance of at least the main groups.

3. The head lengths separate the populations of Prince William Sound from those of the Kodiak-Afognak district and of Kachemak Bay—a distinction of stocks not shown by the vertebral counts.

OTHER CHARACTERS

Besides the structural characters there are other differences between the stocks of herring that while not strictly "racial" differences yet indicate the degree of inde-

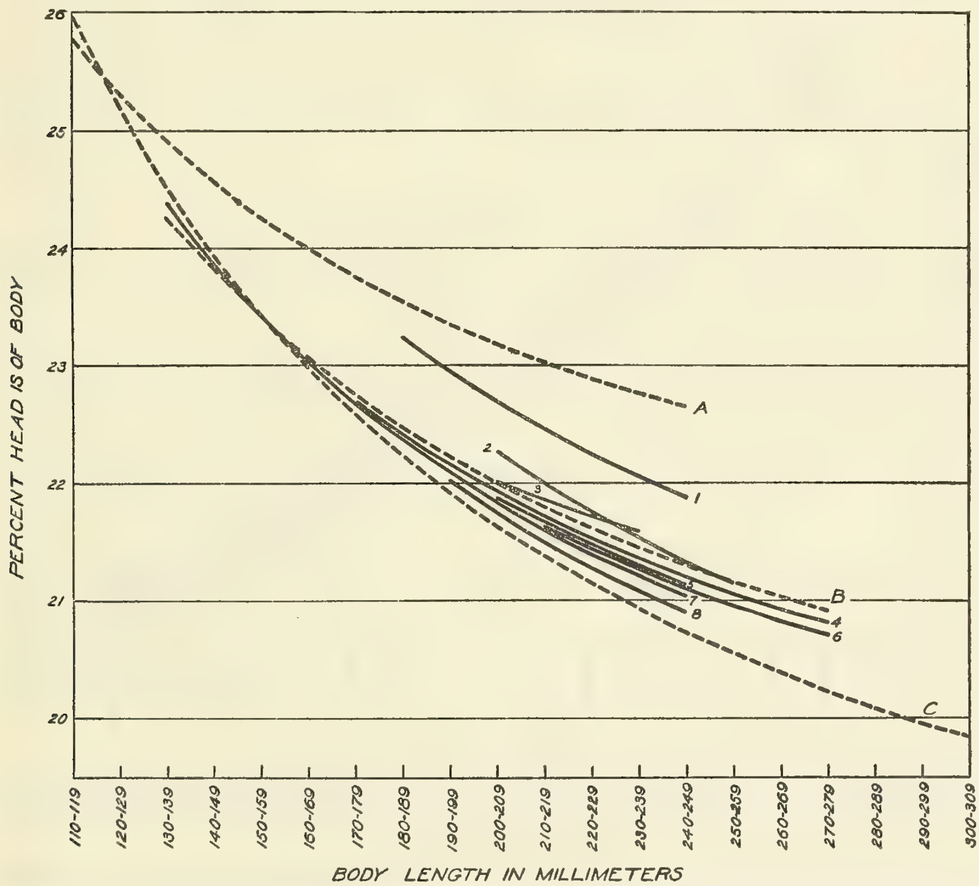

FIGURE 22.—Percentage head length is of body length. Showing: A, Southeastern Alaska; B, Prince William Sound, (1) Naked Island 1927, (2) McClure Bay 1927, (3) Naked Island 1925, (4) Elrington Passage 1925, (5) Macleod Harbor 1927, (6) Eshamy Bay 1926, (7) Elrington Passage 1927, (8) Elrington Passage 1926; and C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove

pendence of the various areas. Since these other "characters," such as growth rate, size and age composition, condition, and spawning season are treated fully in their various sections they will only be alluded to here. The differences in size and age composition (and growth rate) between the herring of Prince William Sound and the other central Alaska localities, for instance, are large enough to indicate the essential independence of Prince William Sound and the areas farther west. And such differences in growth rate as those between Unalaska and central Alaska or Stephens Passage are certainly indicative of the independence of the stocks of herring involved.

CONCLUSIONS

A summary of the conclusions reached by the analysis of each character permits us to say with confidence that the following populations have been demonstrated to be independent: California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Prince William Sound, Kachemak Bay-Shuyak Strait, Shearwater

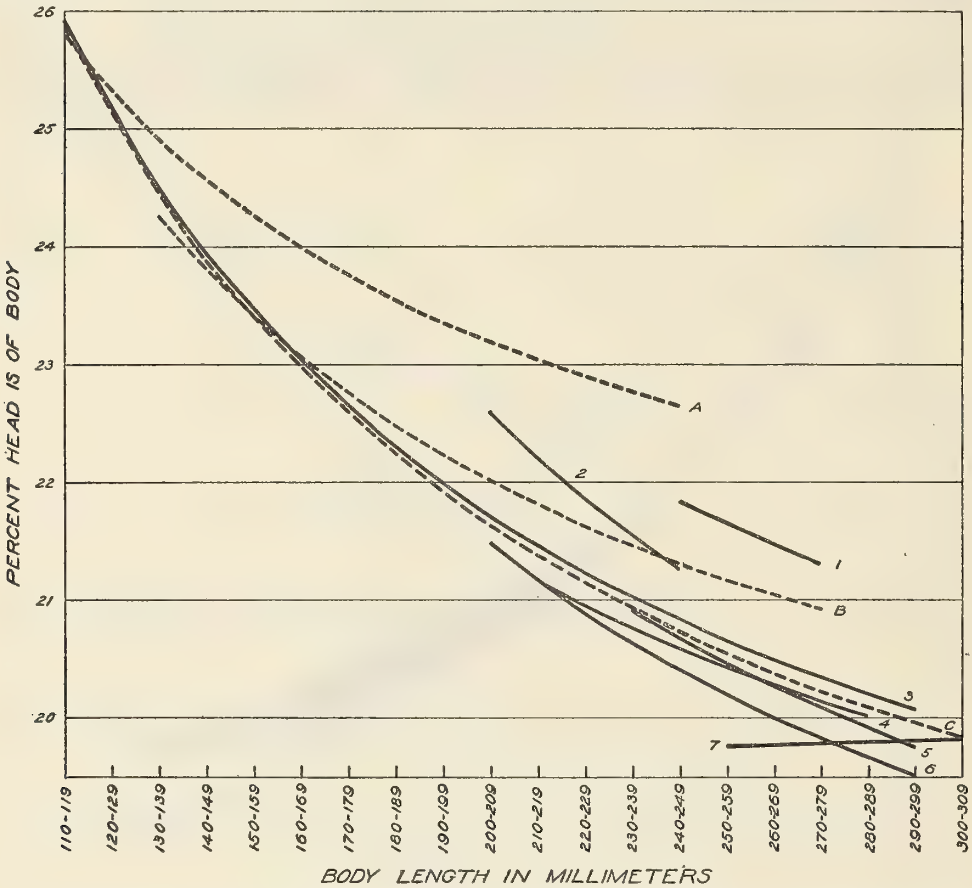

FIGURE 23.—Percentage head length is of body length. Showing: A, southeastern Alaska; B, Prince William Sound; C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove, (1) Dogfish Bay, (2) Halibut Cove 1927, (3) Halibut Cove 1926, (4) Lower Kachemak Bay 1927, (5) Shuyak Strait, (6) Lower Kachemak Bay 1926, and (7) Russian Harbor

Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay. Dogfish Bay may also be a distinct stock, but more data is needed to confirm this.

SPAWNING

SPAWNING HABITS.

The spawning habits of the Pacific and Atlantic herring differ somewhat. The Atlantic herring spawn on the gravelly bottom of the sea, usually in many fathoms of water, and in several cases on banks far from land. The Pacific herring, on the contrary, deposit the adherent spawn thickly on pliable vegetation, such as eel grass and seaweed that grows along the shore. The spawn is all deposited from near the high-tide line to only a few feet below low tide. The Pacific herring has never been known to spawn in deep water. Relative to spawning in shallow water, Fraser says (1922, p. 4):

They come into shallow water at times and feed on the nauplius and cypris larvæ of the barnacles and for days at a time they remain in the barnacle zone. This is most noticeable about spawning time, hence, although it is usually stated that they come into shallow water to spawn, it is possible that the reason of their presence is entirely or largely due to the food supply, the spawning in shallow water being merely incidental.

From San Diego to the Bering Sea the Pacific herring spawn in shallow water, and no evidence has ever been adduced to show that they spawn elsewhere. We do not believe that this is due to the food supply, since examination of the stomachs of herring in Halibut Cove, just previous to and during spawning, showed a complete absence of food, whereas soon after spawning the herring were seen actively feeding.

In the Atlantic there are in many regions two groups or populations of herring known as spring spawners and autumn spawners, according to the season of the year at which they spawn; but in the Pacific, although the time of spawning may vary from December until June according to the locality, there is but one spawning season in each area.

In the Pacific species there seems to be a schooling or migration in the autumn or early winter, at which time the herring come quite near the shore and remain in close proximity to it throughout the winter months until just after spawning. As the herring approach the shore in the fall they often enter small bays and lagoons, many of them with extremely narrow, and often very shallow, entrances. Many of these places are entered annually, and the herring may stay for weeks or months, often not leaving until spawning time. The lagoon at Halibut Cove, described below, is the best example of this, but there are many others. For instance, at Seldovia the herring enter a lagoon, roughly about 500 yards across and about 1 or 2 fathoms in depth. The entrance channel is about a mile long and at low tide runs dry except for a small fresh-water stream that enters the channel about midway of its length. Many years ago this little lagoon was crowded with herring every fall, and a few stragglers still enter it. Other instances can be mentioned, such as the lagoon at the head of Kiavik Bay on Kodiak Island, and the lagoon opposite Russian Harbor on the southwestern tip of Kodiak Island.

The small size of many of the lagoons entered and the numbers of herring that occasionally crowd into these small bays is indicated by the following quotation from Bower and Fassett (1914, p. 127):

Last January at Klawak on the west coast of Prince of Wales Island there occurred an unusually enormous run of herring. So numerous were the fish as they crowded into the bay that hundreds of thousands or even millions were stranded and suffocated. When the tide receded they were left in a solid mass over the beach to a depth in places of several feet.

This habit of entering such small bays and lagoons where they are subject to easy capture may be one factor that causes the herring of Alaska to be readily depleted.

Some rough idea of the relative abundance of herring would well be gained by observing the numbers on the spawning grounds, since at this season all of the mature herring come into shallow water to spawn, where they are easily observed. Only in a few places, such as Fish Egg Island (near Craig) and Sitka Sound in southeastern Alaska, are they known to spawn in any abundance. How, then, as some assert, can one believe that farther offshore there are vast schools of herring yet untouched by the fishery?

OBSERVATIONS ON SPAWNING IN KACHEMAK BAY IN 1926 AND 1927

In the spring of 1926 observations were made on the spawning in Kachemak Bay. (Fig. 24.) The herring in this bay usually enter the lagoon at Halibut Cove some time between October and January of each year and remain at a depth of several

FIGURE 24.—Map of Kachemak Bay

fathoms until nearly time to leave the lagoon to spawn. The lagoon is between 25 and 45 fathoms in depth with steep shores. The entrance channel, which is about a mile long, is very narrow, not over 50 feet wide and 2 or 3 feet deep at low tide. Consequently on big tides the current flows at several miles an hour.

On April 12 a sample of herring, gill netted at a depth of 20 fathoms, was obtained from Halibut Cove lagoon. (Table 26.) All of the herring were mature and most

of the roe contained translucent eggs, although there were a few in which the eggs were still opaque and a very few in a transition stage. The eggs in the herring are opaque during most of the year but turn translucent when fully ripe.

TABLE 26.—*Actual and percentage length of herring taken before and during spawning*

Length in millimeters	Halibut Cove, gill netted, Apr. 12, 1926		Halibut Cove lagoon, beach seined, Apr. 22, 1926		Halibut Cove, beach seined, Apr. 27, 1926		McDonald Spit, spawning, May 12, 1926		Homer Spit lagoon, May 15, 1926		Craig, Mar. 25, 26, and 28, 1928		Stephens Passage, Jan. 27, 1928	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
65–69			2	0.9										
70–74			12	5.2										
75–79			8	3.5										
80–84			2	.9										
85–89														
90–94			1	.4										
95–99														
100–104			1	.4										
105–109													1	0.1
110–114			2	.9									1	.1
115–119			8	3.5									4	.4
120–124			12	5.2									9	.9
125–129			6	2.6									12	1.2
130–134			7	3.0									5	.5
135–139			3	1.3									18	1.8
140–144			8	3.5									14	1.4
145–149			6	2.6									7	.7
150–154			11	4.7									11	1.1
155–159			4	1.7									15	1.5
160–164			2	.9							1	0.3	28	2.9
165–169			3	1.3							2	.7	38	3.9
170–174			5	2.1							10	3.4	62	6.4
175–179			1	.4	2	4.2			1	1.0	13	4.4	69	7.1
180–184			3	1.3	2	4.2			10	10.0	22	7.4	90	9.2
185–189			1	.4			2	1.6	11	11.0	38	12.8	117	12.0
190–194			4	1.7	1	2.1	4	3.2	16	16.0	32	10.7	106	10.9
195–199			3	1.3	1	2.0	8	6.4	18	18.0	36	12.1	98	10.0
200–204			10	4.3	3	6.4	16	12.8	17	17.0	33	11.1	72	7.4
205–209			8	3.5	2	4.2	7	5.6	13	13.0	21	7.0	47	4.8
210–214			3	1.3			7	5.6	6	6.0	18	6.0	33	3.4
215–219			1	.4			6	4.8	1	1.0	25	8.4	28	2.9
220–224			6	2.6	5	10.6	11	8.8	4	4.0	20	6.7	32	3.3
225–229			8	3.5	4	8.5	10	8.0	1	1.0	11	3.7	32	3.3
230–234			2	.9	6	12.8	9	7.2	2	2.0	12	4.1	16	1.6
235–239			5	2.1	5	10.6	8	6.4	1	1.0	3	1.0	8	.8
240–244			5	2.1	2	4.2	3	2.4			1	.3	2	.2
245–249	4	4.0	6	2.6	2	4.2	10	8.0						
250–254	11	11.0	8	3.5	3	6.4	2	1.6						
255–259	8	8.0	8	3.5	1	2.1	3	2.4						
260–264	18	18.0	11	4.7	4	8.5	3	2.4						
265–269	20	20.0	9	3.9	1	2.1	7	5.6						
270–274	13	13.0	5	2.1	1	2.1	1	.8						
275–279	14	14.0	11	4.7	1	2.1	4	3.2						
280–284	5	5.0	6	2.6			4	3.2						
285–289	2	2.0	5	2.1										
290–294	2	2.0												
295–299	2	2.0												
300–304	1	1.0			1	2.1								
305–309														
310–314														
315–319														
320–324			1	.4										
Total	100		233		47		125		100		298		975	

On April 21 we entered the lagoon at high tide. Over all the lagoon the herring were commencing to approach the surface in small schools. About 50 belugas (a species of small white Arctic whale) were raising havoc, and thousands of sea gulls were scattered everywhere. Cormorants, murres, surf scoters, and divers were there in tens of thousands, and scores of bald eagles were circling about.

Reentering the lagoon on the morning of the 22d we discovered that the herring had risen to the surface. An attempt was made to obtain a sample with a 30-fathom beach seine, but the sun was too bright to catch them. That night a sample was taken just inside the narrows with the beach seine. This seine had about 1¼-inch

mesh, stretched measure, so that all sizes were obtained, from several only 3 inches in length to one great herring of 15 inches—the largest encountered in four seasons of field work.

On examining this sample it was noticed that some of the mature herring had spawn which ran easily—the eggs being clear and translucent with a faint yellowish tinge—while other mature herring had eggs practically as large as the translucent ones, but opaque and white. The opaque eggs were found equally in all sizes of fish, making it appear as though age or size does not influence the exact time of ripening of the eggs, but this point, however, will bear further investigation.

During the next few days we watched for the herring to leave the lagoon as they were expected to spawn outside. On the 26th of April we noticed a small school of herring outside of the lagoon in Halibut Cove in the morning and a large school in the evening, which must have come out on the night tide of the 25th, which we were unable to observe.

In the early afternoon of April 27 we entered the lagoon on the flood tide. Acres of herring were breasting the current on the lagoon side of the narrows. As soon as the tide slackened enough for them to make headway against it they commenced to leave and were carried through the channel on the first of the ebbing tide, passing as a steady stream of herring for over half an hour.

Later we learned that a school of herring spawned on the early morning tide of the same day on Homer Spit, a distance of about 7 miles from the lagoon. A few also spawned on Homer Spit on the 1st and 2d of May. We had occasion to visit Homer Spit on May 10 and discovered that the herring had entered a lagoon that extended lengthwise of the narrow gravel spit for about 3 miles and was from 100 to 200 yards in width and a few feet in depth. This lagoon is entered on the Kachemak Bay side of the spit through an entrance about 25 yards wide, so shallow that only about a 17-foot tide flows through it. There is no vegetation on the muddy bottom of the lagoon, which is in reality an immense tide pool. The herring had entered the lagoon on an 18-foot tide, one of the highest tides of the month, causing the water to overflow the banks of the lagoon and covering to the depth of a foot or more much of the short, sparse, wiry grass that fringed them. Not having any other vegetation available, the herring had spawned in this scanty grass above the reach of ordinary high tides.

When the place was visited over a week later the sea gulls were still gathered in thousands, and for a couple of miles the grass was trampled flat. So thoroughly had the birds done their work that it required careful search to find any of the eggs, and nowhere did we find more than one or two to the square inch. Practically all of the eggs found were shriveled by the sun and wind. That many of them could survive a several days' wait for another tide high enough to immerse them appeared impossible.

From the 27th to the 29th of April several schools of herring were observed in Halibut Cove, and on the 29th a sample was seined in the little harbor behind Ismailof Island. These herring were the ripest so far encountered, as in this sample the eggs and milt flowed freely while brailing them into a skiff with a scoop net, whereas in all previous samples they would flow only under a slight pressure.

On the 30th of April the harbor behind Ismailof Island was again full of large herring swimming close to the surface around the shores, but none spawned.

On the following day all of the large herring had departed. The shores of Ismailof Island and Peterson Bay were searched without success. On May 2 we

entered the lagoon, but found little sign of herring; even the gulls and sea birds had left.

For several days the shores of Kachemak Bay, from Bear Cove to Seldovia, were searched without success, but finally on May 12, returning from Homer Spit, a flock of sea gulls was noticed behind McDonald Spit. It was 3 o'clock in the afternoon and high tide when we entered a lagoon behind a sand bar that comprised about a square mile. The water was clear, smooth, and transparent. Schools of herring, showing a marked range in size with the smaller fish in the majority, were swimming about everywhere, exhibiting little fear of our boat. As soon as the tide commenced to fall they approached the shore and rippled the surface as they swam restlessly about. When the tide was about a quarter out they commenced to spawn all around the shores of the lagoon in the eel grass which grew abundantly about a foot in length. Many, left stranded by the falling tide, were being devoured by thousands of sea gulls that had gathered as if by magic.

At first the herring spawned only around the shores, but when the tide had fallen farther, they spawned over the entire floor of the lagoon, which at low tide was covered with about 2 feet of water and carpeted luxuriantly with eel grass. For a while the water was a light brown from the agitated mud, but gradually as the milt became disseminated the water became lighter until finally it was so milky that the eye could penetrate it a bare 6 inches.

In spawning, the female, quivering from head to tail, turns on her side and moves slowly about, often describing a circle, meanwhile extruding the eggs in a thin stream which she rubs against the seaweed and eel grass. The eggs, coated with a gummy secretion, stick instantly to anything with which they come in contact. In like manner the male follows a few inches behind the female covering the attached eggs with a stream of milt.

The herring seemed to be spawning in pairs, but several times we noticed one busily spawning away by itself. The spawning continued throughout the night and they were still spawning the next morning on a rising tide.

On the 15th of May we obtained a sample of herring from Homer Spit that had spawned that morning. It would have been 10 days before the tide would again be high enough to cover their eggs. Many of the short spears of wiry grass not over a millimeter in diameter were covered with eggs until the mass was over a centimeter in diameter. These herring were all small and none were more than 4 years of age and many only 3, so that it was the first spawning for many, if not all, of this school. We were informed that the herring that had spawned at Homer Spit two weeks previously were larger.

For several days the harbor at Halibut Cove had been filled with small herring, so small that on the 17th and again on the 18th of May we could only catch a dozen overnight in a gill net with 3-inch mesh, stretched measure. These few stragglers were extremely ripe. No more herring were obtained in Kachemak Bay until the summer fishing.

In 1926 the herring were not seen leaving the lagoon until the 27th of April, whereas in 1927 when we arrived at Halibut Cove on the 17th of April the herring had already left the lagoon and large numbers had been congregated in the harbor behind Ismailof Island for over a week. The herring did not spawn for another three weeks, and yet, unlike the previous year, they were almost fearless. The harbor must have contained several thousand barrels of herring. They were so crowded and so unafraid that one rubbed the oars against them when rowing.

Figure 33 shows that they were much thinner than in 1926. A great many of them, especially the larger ones, were a little "scabby," having scales missing in spots on their sides and often from the top of the caudal peduncle. To just what extent their apparent fearlessness can be attributed to this emaciated condition can only be surmised. In the three weeks from the 18th of April to the 11th of May the water temperature only increased from 3° C. to 5.5° C., and the herring were not feeding.

On April 21 we entered the lagoon. A small school of belugas and a few sea gulls indicated the presence of a few herring, but it was evident that the main body of herring had left. On the 24th of April we again entered the lagoon. We noticed the sea gulls catching an occasional herring, so we made two hauls with the beach seine without success. The previous year we had caught a few yearling herring between 60 and 80 millimeters in body length mixed among the other herring in the lagoon, but we did not obtain any herring under 2 years of age in many beach seine hauls

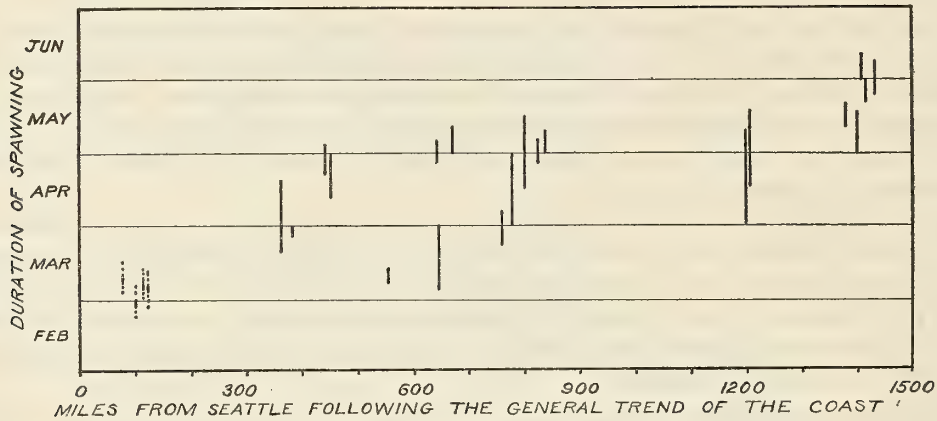

FIGURE 25.—Duration of spawning

made behind Ismailof Island, although not over a mile and one-half from the entrance channel of the lagoon.

The herring remained in the harbor behind Ismailof Island until the 8th of May, when a small school was observed spawning on the western end of the island. On the 9th of May the herring spawned all along the shore from the light on the eastern end of Ismailof Island almost to the entrance to Peterson Bay. This stretch of shore is bold and rocky. The spawn was extruded on the seaweed until in places the shore appeared gray. Immediately after spawning the herring disappeared.

No herring spawned on Homer Spit, but they spawned behind McDonald Spit on the 14th and 15th of May and also about a week previously. A few spawned at Aurora about the 13th of May.

By the 28th of May the eggs were commencing to hatch on Ismailof Island and by June 3 the seaweed was bare of spawn.

TIME AND LOCALITIES FOR SPAWNING

The time of spawning varies considerably between different localities. Figure 25 shows the duration of spawning in some of the places for which we have been given dates that are fairly reliable. This shows a distinct tendency for the herring to spawn later toward the north and west, due possibly to the herring awaiting a favorable water temperature before spawning. There are some few localities, such as

Fish Egg Island near Craig and Sitka Sound, where the herring spawn annually, but most of the evidence shows that the herring do not spawn in exactly the same locality every year. (Fraser, 1916, p. 100.)

The following list of places where herring have been reported to have spawned doubtless contains some inaccuracies both as to time and place, but it is given for what it is worth:

San Diego Bay.—Obtained a sample with ripe spawn on December 13, 1926.

San Francisco Bay.—Carl Hubbs (1925) mentions the breeding season commencing on December 21 and ending on April 17. Scofield (1918) gives January to April.

Scofield (1918) mentions spawning in Tomales Bay from December to March, and also mentions the following places: Morro Bay, Drakes Bay, Bodega Bay, Shelter Cove, and Humboldt Bay.

Captain Freeman informed W. F. Thompson that he had seen herring spawn at the following places in British Columbia: Spider Island, March 20 to April 20; Scudder Point, April 14 to April 30; Burnaby Narrows, April 21 to May 8; Seaforth Channel (south side), last of March; Kitkatla Inlet, about middle of April; Rennell Sound, March 10; Kano Inlet, March 10; Port Neville; White Beach Passage; Quatsino Sound; Nanaimo; Reed Island; Smith's Inlet, Takush; Browning Pass; Shedwell Pass, Bardswell group in narrow channel; Swindle Island; Price Island in narrow channel; Georgetown, between Prince Rupert and Port Simpson; Ikeda Bay (not every year); Jedway (Queen Charlotte Islands); Schooner Point; Cumshewa; Lyle Island in narrows; Skidegate; and Tartoo.

Dr. C. M. Fraser (1916) mentions noting spawning at Nanoose Bay and Departure Bay in 1913. In 1914 he carefully noted the following localities: Yellow Point, February 20; Breakwater Island, February 26; Gabriola Pass, February 26; north shore Pylades Channel, February 26; Pilot Bay to Berry Point on Gabriola Island, March 9 to 11; northeast coast of Gabriola Island from Berry Point to Flat Top Island, March 12 to 13; East side of Gabriola Island, to March 17; Big Qualicum, March 8; entrance Nanoose Bay, March 10; and Ganges Harbor, Saltspring Island March 20.

Edward W. Nelson (1887) describes the spawning in the vicinity of St. Michaels, Alaska, in June.

The writer has had the following list of spawning places reported by various persons:

In southeastern Alaska.—Loring, last of April and first part of May; Port Stewart, last of April and first part of May; Vixen Inlet (Ernest Sound), one week later; Spacious Bay; Morgan's Cove, Trunk Island, Cape Caamano; Union Bay; Meyer's Chuck; Fish Egg Island (Craig), March 27 to April 1 in 1914, March 10 to March 20 in 1915; In Bay on Clam Island, same time; Sugar Point (near Craig), same time; Tonowek Narrows; Big Harbor; Sierra Sound; Rose Inlet; Warmchuck on Heceta Island (occasionally a few); Eleven Mile (near Craig); Tuxekan Pass; Shakan Pass; Hornbrooke Island; Sitka, Silver Bay to Whitestone Narrows, March 20 to April 15; Biorka Island; Killisnoo Lagoon (Angoon), April 1 to end of April; Calico Bay (Kootznahoo Inlet); Hood Bay, May 1 to May 25; Stretchers Cove; Redfish Bay, a little later than Sitka; Port Alexander, May 18; Pybus Bay, May; Seymour Canal at Pleasant Harbor, Mole Harbor and head of the bay, mid April to mid May; Duncan Canal; Port Houghton; Hamilton Bay; Rocky Pass Inlet; Kake; Port Frederick; Idaho Inlet; Mud Bay; Flynn Cove; Tee Harbor, first part of May; Stephens Passage from Point Stephens to about 1½ miles south of Point Lena; Point Louisa; Auke Bay; Coghlan Island; and north end of Douglas Island.

In Prince William Sound.—Ellamar, April; Kniklik, April to middle of May; inside of Fairmont Island, April to middle of May; Knight Island (upper end); Sawmill Bay (few); and both shores of Main Bay between Port Nellie Juan and Crafton Island.

In Cook Inlet.—Port Graham, middle of May; Seldovia Bay; McDonald Spit, first half of May; Tutka Bay, same; Homer Spit, last of April, first of May; Halibut Cove, first of May; Mallard Bay, same; Aurora, same; and Bear Cove, same.

In the Kodiak-Afognak district.—Shangan's Bay, Shuyak Island; Uganik Bay, first part of June; Zachar Bay, June; Shearwater Bay, last of May; and Three Saints' Bay, last of May, first of June.

In the Bering Sea.—Unalaska.

AGE AT MATURITY

The only data obtained that give much indication of the age at maturity in central Alaska were taken from the sample caught with a beach seine in Halibut Cove lagoon. In this sample no 2-year-olds were mature; out of twenty-five 3-year-olds, 13, or 52 per cent, were mature; out of twenty-four 4-year-olds, 20, or 83 per cent, were mature; all of the 5-year-olds were mature.

The sample of mature herring from Homer Spit on May 15 were all 3 and 4 years of age. From the scale readings there were twenty-nine 3-year-olds and sixty-one 4-year-olds, 32 and 68 per cent, respectively. If we take only the mature 3 and 4 year olds from the Halibut Cove lagoon sample we find that 39 per cent of them were 3-year-olds and 61 per cent were 4-year-olds, making the proportions between mature 3-year-olds and mature 4-year-olds in the two samples rather similar.

In Stephens Passage, southeastern Alaska, all 2-year-olds were immature; out of twenty-two 3-year-olds, 19, or 84 per cent, were mature; all of the 4 and 5 year olds were mature.

Comparing Stephens Passage with Halibut Cove, in Stephens Passage 62 per cent more spawned at 3 years and 20 per cent more spawned at 4 years than at

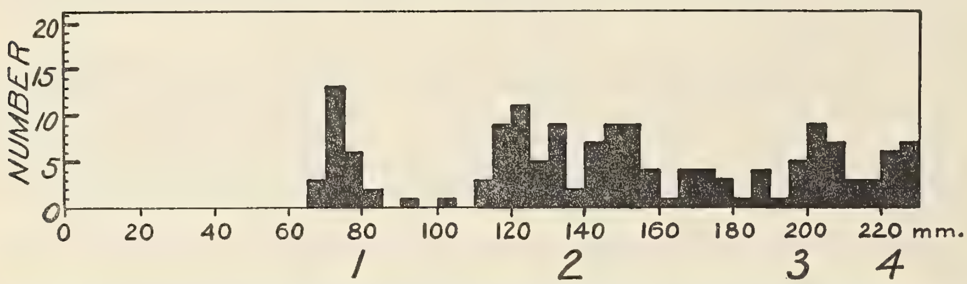

FIGURE 27.—Length frequency of herring under 230 millimeters in length taken in the lagoon at Halibut Cove with a beach seine, April 22, 1926. The large figures show the position of the age groups as determined from scale readings of Halibut Cove samples

Halibut Cove. This is even more remarkable considering the much faster growth rate at Halibut Cove.

AGE AND GROWTH

DETERMINATION OF AGE

A knowledge of the proportions of fish of various sizes in the commercial catch is necessary in determining the causes and extent of the fluctuations in abundance. But information as to the sizes present is chiefly of value in the light of knowledge as to the ages and rates of growth.

We have determined the age of the Pacific herring by the well-known method of making a microscopic examination of the scales and counting the number of annual rings (Fig. 26). Our age determinations among the younger age groups are partially confirmed by size frequencies. Figure 27 shows the length frequencies of herring under 230 millimeters in length, taken in Halibut Cove lagoon, April 22, 1926. The large figures are placed at the mean lengths of the younger age groups as taken from the curve in Figure 29. Figure 27 shows the 1-year group (in this case almost exactly 1 year old) quite distinctly, but the other year groups are not very clearly shown, as the number of specimens is too small. Figure 28 shows the length frequency of 463 Cape Elrington herring taken on August 25, 1925. This curve shows well the 2-year group (in the second summer) between 130 and 160 millimeters. The 2 and 3

FIGURE 26.—Scale of a male, 286 millimeters in body length, taken at McDonald Spit, Kachemak Bay, in August, 1926. The scale shows about 16 annual rings, illustrating the difficulty of age determination in the older fish

year groups do not enter the commercial catch in any numbers, while the 4-year group is well represented. Because of this fact, the 3-year group, being close to the 4-year group and overlapped by it, does not show clearly in the length-frequency curves.

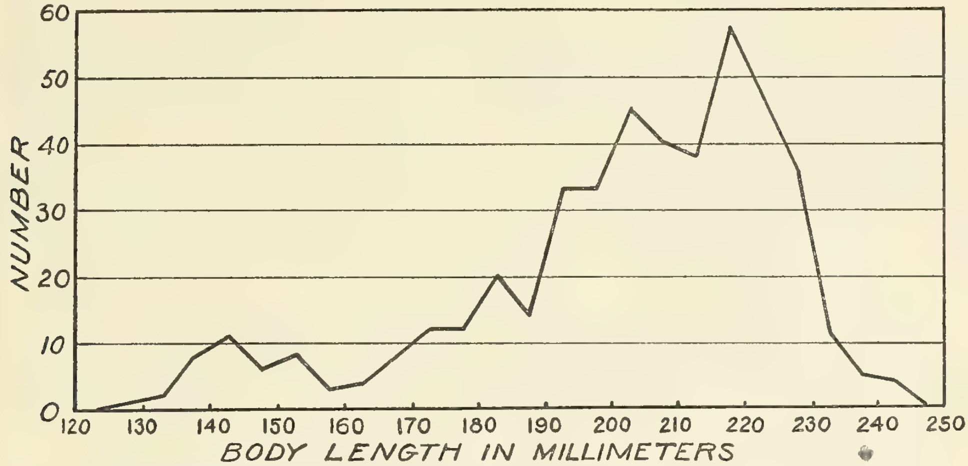

FIGURE 28.—Length frequency of 463 young herring from Cape Elrington, Prince William Sound, August 28, 1925

Otoliths and scales were collected from 50 herring from Elrington Passage, Prince William Sound, on July 6, 1927. Both the scales and the otoliths were legible for 45 of these 50 fish. The results of the readings are tabulated in Table 27.

TABLE 27.—*Relationship of age readings by means of scales and otoliths*

Age as shown by otoliths	Age as shown by scales				
	3	4	5	6	7
	Number	*Number*	*Number*	*Number*	*Number*
3	1				
4		23			
5			6	2	
6				4	3
7					6

The two readings agree except in five cases. In two cases the scale readings showed the fish to be in the sixth year, whereas the otolith readings showed the fish in the fifth year. In three cases fish seven years by the scales were six years by the otoliths. There was no disagreement among the younger age groups. In each case of disagreement it was due to the otolith lacking one year. The otoliths are very small, and the outer rings are so close together in the older fish as to make it difficult to distinguish them by either reflected or transmitted light.

The positive correlation between the readings of the scales and of the otoliths helps in confirming the results of our scale readings and shows that the annual rings on the scales are due to some general physiological change, probably associated with growth or spawning, that affects other hard parts as well as the scales.

During the middle of April, at Halibut Cove, the last ring had not yet formed on many of the scales but was barely discernible on the majority. This is in accordance with Lea's results with the spring spawning herring of Norway (1911). On following the growth of the herring in one locality throughout the year he found that

during April the percentage of fish showing a ring near the very edge of the scale increased steadily until all had it. At Halibut Cove the herring spawn during the last part of April and May. In a sample of spawning herring from San Diego Bay in December, the ring could barely be discerned on a small percentage of the fish.

The scale reading presents some difficulties. As just stated, the ring seems to form about the time of spawning, which would indicate that it is due to the growth of the herring being almost or completely at a standstill at that time. The clearness of the ring would thus depend a great deal on how completely and for how long a time the growth was retarded.

Thompson (1917) describes in some detail the difficulties that he encountered in attempting to read the scales of the herring in British Columbia. He mentions finding a winter zone in which the circuli seem to differ from the remainder. The inner margin of this zone tends to be marked by a "check" of some distinctness, but the winter mark is formed at the outer margin of this zone. He says that this is so often met with that it can not be regarded as otherwise than a normal phenomenon. Other difficulties were exceedingly wide summer zones, numerous more or less distinct "checks," and the uncertainty of distinguishing the winter rings near the margin of scales of older fish.

We have met with similar difficulties, but judging from Thompson's text and plates the scales of Alaska herring are very much clearer than those of British Columbia. The scales of the San Diego Bay herring are slightly less clear than those of Alaska.

One difficulty met with in the very old fish, besides the difficulty of distinguishing between the marginal rings, is that of distinguishing the first and often the second annual ring of the scale. Whether this is due to the more numerous layers of scale substance in the older fish changing the refraction of light is uncertain.

All of the samples contained fish with well-defined rings on their scales, likewise all of the samples showed fish with regenerated scales, which are worthless for age determinations. The proportion of regenerated scales on the individual fish varied greatly, so that in reading the age of an individual from two to a dozen scales were usually examined, this often being necessary in order to obtain ones that were fully legible. For this preliminary report we have read chiefly scales from central Alaska. (Table 33.)

GROWTH RATE

A knowledge of the rates of growth in the various localities is desirable because of its many applications. Whether the difference in average size between any two localities is due to a difference in rate of growth or to a difference in the age composition (possibly due to a reduction of the numbers of older fish in one of the localities) is important in studying depletion. The differences in growth rate are also a valuable aid in studying the independence of areas, as, where the differences are great, it shows a lack of migration. For instance, the differences in growth rate between Unalaska and Stephens Passage herring are enormous, those at Unalaska (Dutch Harbor) at 6 years of age being 6½ centimeters greater in body length than those of Stephens Passage.

To grasp the real significance of these differences in growth rate the comparisons should be made on the basis of weight, as any given increase in length represents a far greater amount of growth in a larger fish than in a smaller fish. The weight varies a great deal within the same locality at different seasons but only slightly between different localities at comparable seasons of the year. Therefore, not

having weight-length curves at comparable seasons for all of these localities, we shall use the weight-length curve for Halibut Cove (fig. 33) in making comparisons between the weight for any given age in different localities shown in Figure 29.

Using these weights, at 6 years of age the Stephens Passage herring would weigh 91 grams, the Dutch Harbor herring 253 grams, or 2.8 times as much. Since the smallest-sized herring packed as a "medium" is over 10½ inches in total length, or about 225 millimeters in body length, and 170 grams in weight, the Stephens Passage herring do not attain a size suitable for packing as "mediums" until about 9 or 10 years of age. On the other hand, the Dutch Harbor herring at only 6 years of age are being packed chiefly as "large" (11½ to 12½ inches). The differences between

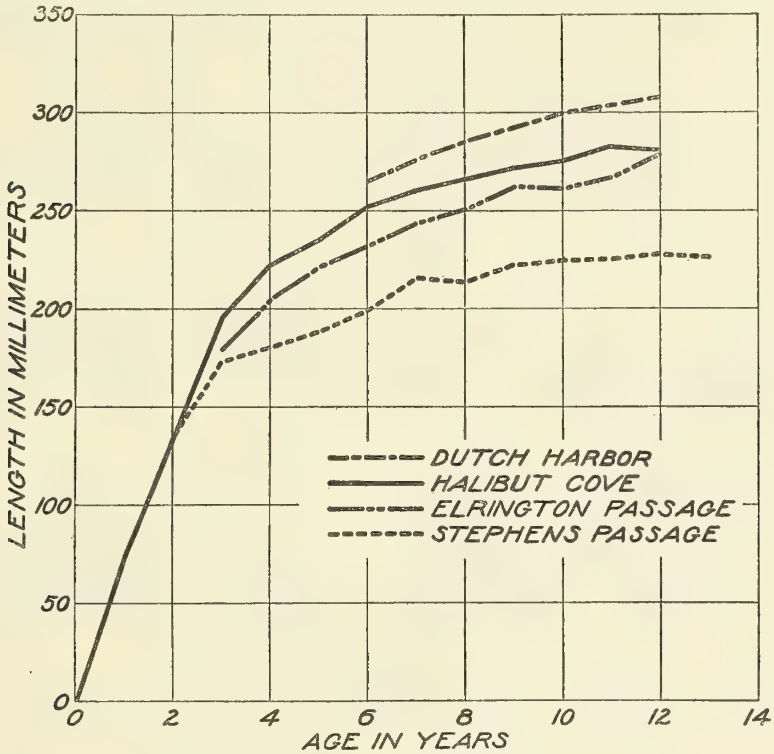

FIGURE 29.—Growth curves showing the age-length relationship

the other localities are not so great, 6-year-old Dutch Harbor herring being only about 19 per cent heavier than those of Halibut Cove and 62 per cent heavier than those of Elrington Passage.

The evidence shows that the growth curve for Stephens Passage is not representative of southeastern Alaska as a whole. If the data for Larch Bay were plotted (Table 28), the curve would come very slightly below that of Elrington Passage. Since the Larch Bay sample was preserved in formalin the curve would probably be very close to that of Elrington Passage, if one allows a trifle for shrinking of the length.

Farther south in British Columbia, Thompson (1917, p. S64) obtained data at Nanaimo and Point Grey in the Strait of Georgia, and at Kildonan on the west coast of Vancouver Island, that show them to have a rate of growth comparable

to that of Stephens Passage. A very few age readings from San Diego Bay indicate a rate of growth but slightly higher than that of Stephens Passage.

It may be pointed out that although there seems to be a tendency for slower growth to the southern and eastern portion of the range, it also seems that the growth rate is in each general area slower in inclosed waters. To illustrate, the Prince William Sound growth rate is slower than that of Shuyak Strait, and the Stephens Passage rate of growth slower than that of Larch Bay.

Similar results have been obtained in the study of the European herring, those from the White Sea, the Lysefjorden (West Norway), the Zuider Zee, and the east coast of Sweden being slow growing, while those from the western North Sea, the Atlantic Ocean, around Iceland, and the outside waters of western Norway are all fast growing. (Hjort, 1914.) The herring in some of the fjords on the Baltic coast of Sweden were found by Hessle (1925) to be slower in growth than those of the main Baltic.

The growth-rate curves shown in Figure 29 are not constructed from calculated growths, but each point in the curve is the average length of the fish actually taken at that age. Growth curves based on scale measurements will be presented in a later report.

TABLE 28.—*Observed lengths at each age in millimeters*

Age (years)	San Diego Bay,[1] December, 1926	Stephens Passage	Larch Bay,[1] August, 1927	Halibut Cove, April 1926	McDonald Spit, May, 1926	Homer Spit, May, 1926	Kachemak Bay, August, 1926	Shuyak Strait, July, 1925 and 1926	Dogfish Bay, August, 1925	Naked Island, August, 1925	Elrington Passage, June–August, 1925 and 1926	Dutch Harbor, August, 1928
1				74.1								
2		134.9		134.0			131.0					
3		170.3		195.7	199.1	195.9	[2] 188.7			[2] 192.5	179.2	[2] 190.0
4	[2] 200.0	180.0	203.3	221.5	222.7	201.1	220.2	[2] 220.0		205.4	205.0	
5		187.7	218.2	234.7	235.7		224.9	241.0	[2] 220.0	222.9	220.8	
6	[2] 213.7	[2] 198.7	223.0	252.1	[2] 260.0		252.5	252.2	[2] 235.2	[2] 229.0	231.4	265.2
7	217.0	[2] 215.3	235.8	260.2	252.7		263.0	252.0	[2] 241.0	[2] 240.5	243.0	276.1
8		213.2	234.8	265.9	[2] 265.5		268.1	264.5	[2] 255.0		250.0	[2] 284.8
9	226.8	221.8	[2] 232.0	271.8			272.6	271.2	261.4	[2] 268.0	261.6	
10		[2] 224.2		275.2	276.8		273.7	272.7	263.3	[2] 260.0	261.0	[2] 299.3
11		[2] 225.0		282.8	269.8		279.4	275.2	262.6	[2] 267.0	266.9	
12		[2] 227.5	[2] 243.0	[2] 281.7	[2] 282.0		284.1	287.5	266.8		[2] 279.0	[2] 307.5
13		[2] 226.0					285.4	[2] 277.5				
14								[2] 282.7				
15							[2] 290.0					
16												
17							[2] 286.0					
18												
19				[2] 320.0								

[1] Preserved in formalin. [2] Average contains a frequency of less than 5.

CONDITION

CONDITION FACTOR

It is desirable to know the condition or "fatness" of the herring at different seasons and in different localities since the value of the raw herring depends to a very large extent on the condition. It is a great economic waste to catch herring for oil and fish meal when the oil content is low, or to catch herring for pickling and discard large fish that are too thin. If the changes in the condition of the herring are known, regulations for opening and closing the fishing season may be so framed as to reduce this waste to a minimum thus aiding in the conservation of the supply. For these reasons the investigation of the condition is of great importance so that accurate information may be available.

Weights have been taken to enable us to follow the changes in the condition of the fish during the seasons of 1926 and 1927. Owing to the erratic appearance of herring in central Alaska, we have been unable to obtain a complete series of weights over the entire season in any one locality for use as a basis of comparison to discount seasonal and size changes.

We have data for both years for Halibut Cove, lower Kachemak Bay, and Elrington Passage and vicinity in Prince William Sound. We also have weights for Shuyak Strait and Eshamy Bay in 1926, and from McClure Bay, Naked Island, and Macleod Harbor in 1927.

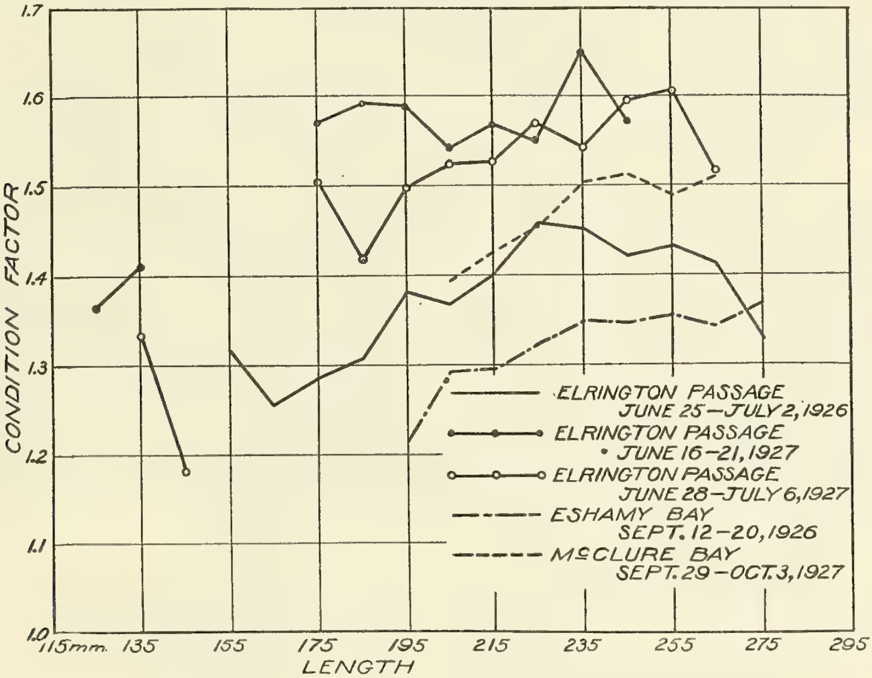

FIGURE 30.—Condition factor for herring in Prince William Sound

As a standard of comparison we have shown the relation of the weight to the length by using a condition factor obtained by the formula:

$$K = \frac{100W}{L^3}$$

in which K is the condition factor, W the weight, and L the length. The weight does not increase exactly as the cube of the length, but this factor is valid for comparing fish of the same length. (Clark, 1928.) Besides a difference throughout the season and in different localities, there is also an annual variation, not only in the time when a certain condition is reached in each individual but also in the maximum condition obtained. The condition factor naturally changes with the size of the fish represented in the catches.

In Prince William Sound the fish were in better condition in 1927 than in 1926, as shown in Figure 30. During the period from the 25th of June to the 2d of July, 1926, in Elrington Passage and vicinity in Prince William Sound, the herring up to 225 millimeters in body length were in fair condition and contained an abundance of

"belly fat" or ister (fat stored in the body cavity among the entrails), but the herring above 225 millimeters in body length in the same samples contained very little fat and were rather thin. In the female gonads from one to half a dozen ripe eggs were often found, and the male gonads had blood clots. Both the female and the male gonads were flabby. All of these facts tend to show that it was probably not long since they had spawned.

The data for Elrington Passage for 1927 are shown as two separate curves. The first of these curves, from June 16 to 21, 1927, was taken on the average about 10 days

FIGURE 31.—Condition factor for herring in Kachemak Bay

earlier than the 1926 curve; while the second curve, from June 28 to July 6, 1927, was taken about 3 days later than the 1926 curve. Both of the 1927 curves are considerably above the 1926 curve.

The same superior condition of the 1927 samples is shown elsewhere in Prince William Sound. In Eshamy Bay, from September 12 to 20, 1926, the herring were all rather thin with only a trace of ister; a few, especially the larger ones, were too thin to salt. No herring were caught in Eshamy Bay in 1927, but we have samples from McClure Bay. The two localities are only 12 miles apart, so they can be compared for the two years. The McClure Bay samples were taken from September 29 to October 3, 1927, an average of two weeks later than the Eshamy Bay samples of 1926,

but the Eshamy Bay fish were rather thin while the McClure Bay fish contained an abundance of ister and were in excellent condition.

In 1927 the herring in Elrington Passage in June and the first part of July attained a fair condition earlier than in 1926, and in McClure Bay they were in excellent condition at the 1st of October in 1927, while in Eshamy Bay they were thin in the middle of September in 1926. Thus it appears that in Prince William Sound in 1927 the herring were in good condition for a much longer time than in 1926 and probably also attained a much higher maximum condition. Only study for several years can tell which year comes closer to being normal.

Similar comparisons for Kachemak Bay are given in Figure 31. Halibut Cove herring were in better condition just before spawning the last part of April, 1926, than the last part of April and first part of May, 1927, just the reverse of conditions in Elrington Passage. Herring from lower Kachemak Bay for the last part of August were quite similar in condition in 1926 and 1927. In September, 1927, the condition, while still excellent, had commenced to fall slightly.

Samples were taken at Shuyak Strait on July 15 and August 5, 1926. The herring were in excellent condition and their condition-factor curve is very nearly the same as that for lower Kachemak Bay from August 19 to 30, 1926.

Besides a difference in condition in different years and at different times, there is also a difference between localities. Samples were obtained from Naked Island and from Macleod Harbor in Prince William Sound on the 12th and 13th of June, respectively. (Table 29.) The sample from Macleod Harbor was but little below the samples from Elrington Passage taken a few days later, whereas the herring from Naked Island were much lower. The latter herring were quite thin, containing no ister, and had spawned on the webbing of the pounds in which they were confined.

TABLE 29.—*Condition factor and weight at different lengths in 1926 and 1927*

[Points marked with an asterisk have a frequency of less than five]

(A) CONDITION FACTOR

Length in millimeters	Halibut Cove, Apr. 12–27, 1926	Halibut Cove, Apr. 25, May 4 and 11, 1927	Shuyak Strait, July 15–Aug. 5, 1926	McDonald Spit, Kachemak Bay, Aug. 19–30, 1926	McDonald Spit, Kachemak Bay, Aug. 10, 1927	McDonald Spit, Kachemak Bay, Aug. 23, 24, 25, and 27, 1927	McDonald Spit, Kachemak Bay, Sept. 8–21, 1927	Naked Island, June 12, 1927	Macleod Harbor, June 13, 1927	Elrington Passage, June 25–July 2, 1926	Elrington Passage, June 15, 17, and 21, 1927	Elrington Passage, June 28–July 5 and 6, 1927	Macleod Harbor, July 1–9, 1927	Eshamy Bay, Sept. 12–20, 1926	McClure Bay, Sept. 29, 30, Oct. 2 and 3, 1927
60–69	*0.728														
70–79	*.626														
80–89	*.570														
90–99	*.688														
100–109	*.864														
110–119	.888										*1.390				
120–129	.855			*1.152				0.884	*1.389		1.366				
130–139	.853	*0.956		*1.016					*1.502		1.411	1.334			
140–149	.859	*1.075		*1.050						1.410		1.181			
150–159	.867								*1.126	1.319		*1.244			
160–169	1.011	*1.074		*1.291				*1.074	*1.440	1.256	*1.526	*1.538	*1.563	*1.202	
170–179	1.037	.993						*1.343	1.356	1.286	1.569	1.504	1.500	*1.101	
180–189	1.053	.965		*1.327				1.250	1.456	1.308	1.593	1.420	1.463	*1.263	*1.303
190–199	1.094	1.021				*1.575	*1.604	1.260	1.471	1.381	1.591	1.499	1.516	1.212	*1.312
200–209	1.128	1.076		*1.364	1.650	*1.438	1.338	1.183	1.464	1.367	1.543	1.523	1.450	1.291	1.393
210–219	1.097	1.118		*1.363	1.581	1.537	1.474	1.291	*1.550	1.400	1.569	1.526	1.435	1.295	1.425
220–229	1.237	1.129		*1.446	1.482	1.533	1.513	1.347	*1.568	1.459	1.551	1.569	1.657	1.322	1.453
230–239	1.282	1.110	1.433	1.412	1.554	1.547	1.525	1.312	*1.553	1.450	1.650	1.542	*1.529	1.349	1.502
240–249	1.362	1.110	1.564	1.543	*1.606	1.569	1.542	1.345	*1.418	1.421	1.571	1.597	*1.490	1.346	1.511
250–259	1.386	1.146	1.532	1.520	1.603	1.543	*1.496	*1.346		1.433	*1.446	1.607	*1.552	1.355	1.489
260–269	1.380	1.169	1.618	1.596	1.501	1.624	1.541	*1.255		1.412	*1.481	1.517		1.343	1.509
270–279	1.413	*1.231	1.625	1.615	*1.697	1.594	1.575	*1.174		1.328	*1.463			1.369	*1.306
280–289	1.448	1.132	1.547	1.585	1.627	1.559	1.485								*1.563
290–299		*1.152	1.554	1.553	*1.577	*1.460									
300–309				1.597		1.522	*1.556								
310–319				*1.269											

(B) WEIGHT

60–69	2.0														
70–79	2.7														
80–89	*3.5														
90–99	*6.0														
100–109	*10.0														
110–119	13.5										*18.5				
120–129	16.7			*22.5				*17.0	*24.0		23.6				
130–139	21.0	*21.0		*25.0					*33.0		31.0	29.3			
140–149	26.2	*29.5		*32.0						*43.0		32.4			
150–159	32.3								*38.0	49.1		*42.0			
160–169	45.4	*44.0		*58.0				*44.0	*59.0	56.4	*62.5	*63.0	*64.0	*54.0	
170–179	55.6	48.8						*66.0	66.6	68.9	77.1	73.9	73.7	*59.0	
180–189	66.7	56.3		*84.0				70.0	84.9	82.8	92.9	82.7	85.3	*80.0	*76.0
190–199	81.1	70.0				*108.0	*110.0	86.4	100.9	102.4	109.1	102.8	104.0	89.9	*90.0
200–209	97.2	86.1		*117.5	*132.0	*115.0	107.0	94.6	117.1	117.8	123.4	121.8	116.0	111.2	111.4
210–219	*109.0	103.5		135.5	146.4	142.3	136.5	119.6	*143.5	139.1	145.3	141.3	132.9	128.7	132.0
220–229	140.9	120.2	*144.0	*164.7	157.8	163.2	161.1	143.4	*167.0	166.2	165.1	167.1	176.4	150.6	154.7
230–239	166.4	135.1	*186.0	183.3	189.1	188.2	185.6	159.6	*189.0	188.2	200.8	187.6	*186.0	175.1	182.8
240–249	200.3	153.5	230.0	221.2	*222.0	216.9	213.2	185.9	*196.0	209.0	217.2	220.8	*206.0	197.9	208.9
250–259	229.8	179.0	254.0	252.0	250.4	241.1	*233.8	*210.3		237.6	*226.0	251.1	242.5	224.6	232.6
260–269	256.8	205.5	301.0	297.0	263.8	285.5	270.8	*220.5		262.8	*260.3	266.6		250.0	265.3
270–279	293.8	*242.3	338.0	335.8	*334.0	313.8	310.0	*231.0		276.1	*288.0			284.7	*257.0
280–289	335.2	248.6	358.0	366.9	357.2	342.2	326.4								*343.0
290–299	*333.0	*281.0	399.0	398.8	*384.7	*356.0									
300–309	*372.0		*434.0	453.1		*411.0	*420.0			*315.0					
310–319				*435.5											
320–329	*462.0														

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LENGTH WEIGHT RELATIONS

Figures 32 and 33 show the length weight curves for some of the localities smoothed by the method of least squares, using the equation $W=KL^x$, where W=weight, L=length, and K and x=constants.

The equations for all of the curves are:

Halibut Cove:	
Apr. 12–27, 1926	$W=.0584\ L^{3.63}$
Apr. 25–May 11, 1927	$W=.0371\ L^{3.43}$
Lower Kachemak Bay:	
Aug. 19–30, 1926	$W=.0272\ L^{3.43}$
Aug. 10, 1927	$W=.0125\ L^{3.19}$
Aug. 23–27, 1927	$W=.0126\ L^{3.19}$
Sept. 8–21, 1927	$W=.0210\ L^{3.34}$
Red Fox Bay, Shuyak Strait: July 15–Aug. 5, 1926	$W=.0651\ L^{3.01}$
Elrington Passage and vicinity:	
June 25–July 2, 1926	$W=.0123\ L^{3.18}$
June 16–21, 1927	$W=.0177\ L^{3.31}$
June 28–July 6, 1927	$W=.0262\ L^{3.42}$
Eshamy Bay: Sept. 12–20, 1926	$W=.0185\ L^{3.28}$
McClure Bay: Sept. 29–Oct. 3, 1927	$W=.0240\ L^{3.38}$
Naked Island: June 12, 1927	$W=.0382\ L^{3.49}$
Macleod Harbor:	
June 13, 1927	$W=.0369\ L^{3.54}$
July 1–9, 1927	$W=.0169\ L^{3.29}$

Neither the condition factor nor these values of K and x can be used for racial studies until a far more thorough study of them is made for each race. A constant difference between the fish of two localities may be due to environmental conditions only, but this difference may be of value in the study of migration.

CLEANED WEIGHT

In comparing the weights of fish of any given length by Figures 32 and 33, it must be borne in mind that a considerable difference in weight is caused by either gonads or ister. Figure 34 shows the total weight, cleaned weight, and gonad weight for 1927 for Halibut Cove, April 25–May 11, and for lower Kachemak Bay, August 23–27. Note that the actual difference in weight resulting from cleaning for each of the two localities is very similar, despite the fact that the Halibut Cove material was taken just before spawning. In the Halibut Cove data most of the difference between the cleaned weight and the total weight is in the weight of the gonads. In the lower Kachemak Bay data the gonads are but slightly developed, and the difference between the cleaned weight and the total weight is caused chiefly by a large amount of ister in the body cavity.

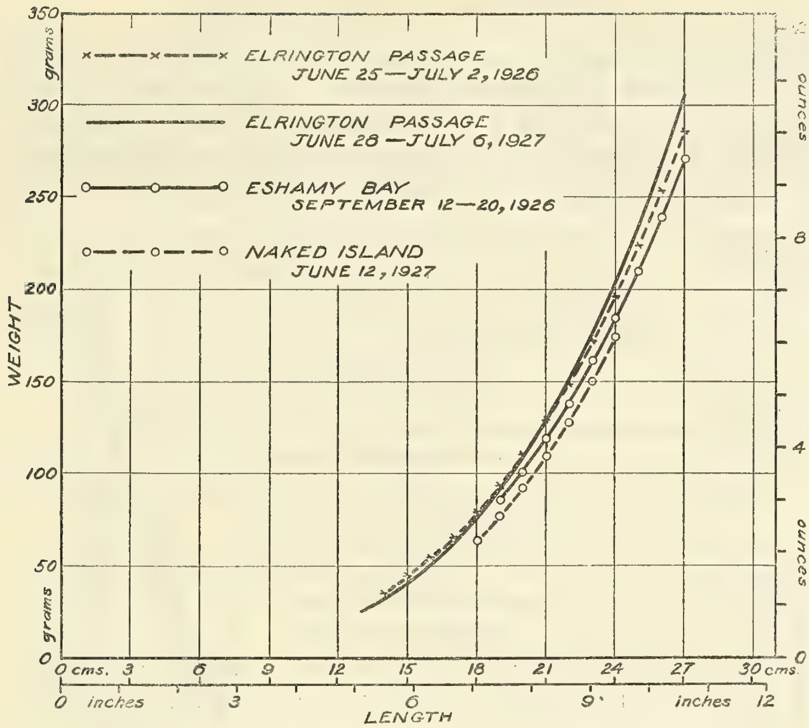

FIGURE 32.—Length-weight curves for herring in Prince William Sound

TABLE 30.—*Cleaned weight at different lengths*

Length in millimeters	Halibut Cove, May 4 and 11, 1927	Lower Kachemak Bay, Aug. 10, 1927	Lower Kachemak Bay, Aug. 23, 24, 25, 27, 1927	Lower Kachemak Bay, Sept. 8 and 21, 1927	South Bay, Naked Island, June 12, 1927	Macleod Harbor, June 13, 1927	Prince of Wales Passage, June 21, 1927	Procession Rocks, June 28, 1927	Procession Rocks, July 5–6, 1927	Macleod Harbor, July 9, 1927	McClure Bay, Sept. 29–30, Oct. 2–3, 1927
120–129					[1] 16.0	[1] 21.5					
130–139						[1] 28.0		24.8			
140–149								[1] 30.0			
150–159						[1] 34.0		[1] 35.0			
160–169					[1] 38.0	[1] 50.5					
170–179	[1] 45.3					58.7	[1] 63.8	[1] 65.0	65.0	[1] 65.3	
180–189	[1] 47.7				[1] 66.7	74.6	78.9	75.5	72.4	74.9	[1] 68.0
190–199	[1] 64.0		[1] 95.0	[1] 94.0	76.2	87.2	91.9	89.3	88.9	91.7	[1] 79.3
200–209	70.6	[1] 111.0	[1] 99.5	94.7	83.9	100.3	107.0	105.7	104.3	99.9	98.1
210–219	88.4	129.0	125.2	121.0	[1] 103.7	[1] 128.5	[1] 124.0	[1] 136.0	118.3	107.8	117.3
220–229	95.1	136.1	141.8	139.8	128.6	143.0	[1] 139.0	144.6	141.5	[1] 165.0	135.0
230–239	107.9	162.6	163.2	162.1	140.3	[1] 145.0	[1] 171.5	[1] 120.0	162.2		159.4
240–249	123.3	[1] 189.7	187.9	183.9	170.7	[1] 169.0	[1] 151.0	[1] 180.0	180.7	[1] 156.0	179.0
250–259	[1] 137.3	213.0	209.5	[1] 200.0	[1] 183.0		[1] 181.0		[1] 211.0		203.3
260–269	[1] 167.8	226.0	246.8	236.0	[1] 195.0				[1] 226.7		227.2
270–279	[1] 194.3	[1] 289.0	272.7	252.9	[1] 207.0						[1] 243.7
280–289	[1] 185.0	306.5	298.8	284.4							[1] 343.0
290–299	[1] 236.0	[1] 327.3	[1] 312.8								
300–309			[1] 367.0	[1] 370.0							

[1] Averages contain a frequency of less than 5.

CONCLUSIONS

1. In Prince William Sound the date at which the herring reach a condition suitable for packing or commence to be rather thin for packing in any certain locality will vary at least two weeks in different years.

2. There may be a considerable difference in the condition attained in different localities in Prince William Sound by the same date.

3. The maximum condition attained will probably vary considerably from year to year.

CONDITION OF THE FISHERY

It is our purpose to discover how the species is faring under the changed conditions of survival incident to an intensive fishery. In determining this condition we must first discover what changes in abundance have occurred. Our only measure of the abundance is obtained from the catch of the commercial fishermen which is influenced by various economic factors and by changes in the amount and kind of

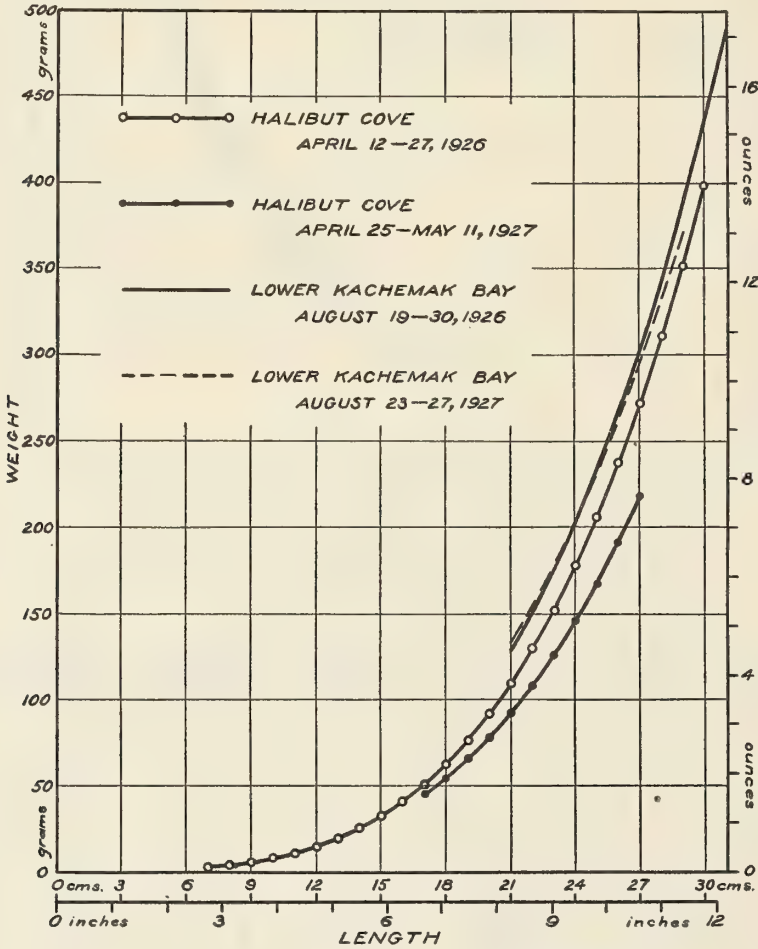

FIGURE 33.—Length-weight curves for herring in Kachemak Bay

gear used. Hence, in determining the actual abundance, as shown by these records, one can not use the total catch, but must employ some other measure of abundance, such as the catch per unit of fishing effort. Furthermore, the catch of each area must be segregated and analyzed separately, for the study of the independence of areas (see p. 246) has shown that, in the Pacific herring, the population of each region is independent of those of neighboring regions.

In determining the causes of these changes in abundance within each area a knowledge of the size and age composition of the catch is fundamental. In many species of fishes, due to variations in hydrographic or other conditions, the amount of success attending spawning varies greatly from year to year, it being quite usual

to have periods of years when but few young survive, and occasional years in which exceptionally large numbers of young survive. These unusually abundant year classes, termed "dominant" year classes, have been found in the cod, the plaice, the mackerel, and in the very close relations of the Pacific herring—the California sardine (Higgins, 1926; Scofield, 1926) and the Atlantic herring (Hjort, 1914; Lea, 1919, 1924)—and the presence of these dominant year classes causes natural fluctuations in abundance. A temporary decline in abundance, due to the passing out of the catch of a dominant year class, must not be confused with a decrease due to over-fishing. Therefore, in attempting to explain the fluctuations in abundance of the

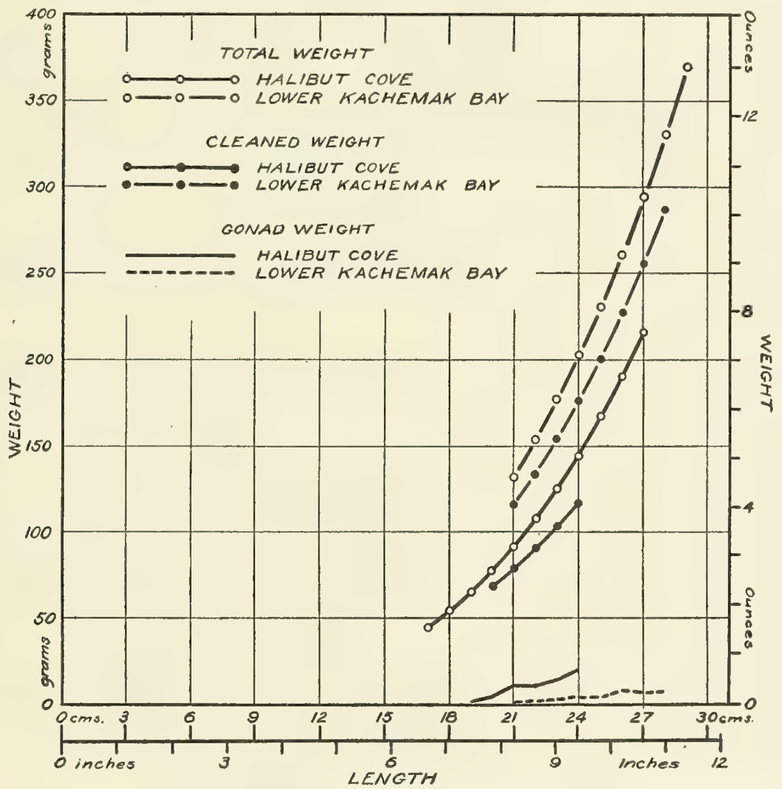

FIGURE 34.—Total weight, cleaned weight, and gonad weight for herring in Halibut Cove and lower Kachemak Bay for 1927

Pacific herring, one of our first aims was to demonstrate the existence or nonexistence of this phenomenon of dominant year classes and its effect on the catch.

COMPOSITION OF THE CATCH

SAMPLING FOR SIZE AND AGE COMPOSITION

In order to connect the changes in the composition of the catch with fluctuations in the yield of the fishery, it is necessary to follow such changes as may occur in the size and age of the population.

For this knowledge of the herring population we must depend upon the portion taken by the fishermen. Of this portion consisting of many thousands of barrels of fish only a few thousand individuals can be measured. Hence, the question naturally arises, How accurately do these few individuals represent the population?

Sette (1926) made a study of this sampling problem with the California sardine (*Sardina cærulea*) at Monterey. He obtained a very complete series of samples throughout the season and made the assumption that these represented the commercial catch. He then endeavored to discover by mathematical means how frequently samples need to be taken in order to represent the series with reasonable accuracy. He found that by taking samples at least semiweekly the desired result could be obtained.

No such series of samples is available for the herring. The herring "runs" are more erratic than those of the sardine, because in many localities the herring can be sampled for only two or three months out of the year, and the total catch of the year may be made on as few as 10 different days. Indeed, in Red Fox Bay, Shuyak Strait, in 1926, the whole catch of about 13,000 barrels was taken in two nights' fishing. Sampling twice a week might be theoretically correct, but under such conditions it is impossible from a practical standpoint, except perhaps for the duration of a "run."

With the herring it is highly probable that in each locality a much smaller population is sampled than with the sardine. So far but very little evidence has been found to show the existence of local races in the California sardine (Hubbs, 1925, p. 12), while studies have shown the Pacific herring to be divided into many local races. The catch landed in a given port may come from several of these, making the sampling of the herring much more complex.

These facts tend to show that in the case of the Pacific herring sampling can not be made as exactly as in that of the California sardine, so that in order to prove the validity of our sampling a more complete dependence must be placed upon the repeated occurrence of consistent variations (Thompson, 1926a). The inability to obtain samples over a long period during each season will make it less likely that our samples will represent the same portion of the population year after year, thus decreasing our chances of proving the consistency in occurrence of any variations and making it more difficult to foretell in advance what fluctuations in abundance may be expected.

Even if it were true that the commercial catch is taken each year from the same section of the population, it might be difficult to demonstrate clearly the exact manner in which dominant year classes would come into evidence. Thus in the sardine of California the dominant year classes affect the commercial take unequally at different sizes and ages, and prophecy of the catch is thereby limited. (Thompson, 1926a.)

EVIDENCE OF DOMINANT YEAR CLASSES

In order to prove the existence or nonexistence of dominant year classes, samples are needed over a period of years from one locality. (Table 31.) The longest period for which consecutive samples are available extends from 1924 to 1927. These were taken in, or in the immediate vicinity of, Elrington Passage, one of four channels connecting the western side of Prince William Sound with the open ocean. All of the data for 1924 and a portion of those for 1925 consist only of length measurements, which were obtained from Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries. Ages are available for a portion of the 1925 data, and for most of those of 1926 and 1927.

TABLE 31.—*Length frequencies of summer herring*

Length in millimeters	Southeastern Alaska		Elrington Passage						Macleod Harbor				Eshamy Bay	
	1925		1925		1926		1927		1927		1928		1926	
	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent
100–104									1	0.5				
115–119							2	0.3						
120–124							2	.3	1	.5				
125–129							10	1.7	1	.5				
130–134							8	1.4						
135–139							7	1.2	1	.5				
140–144							12	2.1						
145–149					2	0.2	2	.3						
150–154					5	.5	1	.2	1	.5	2	0.6		
155–159					8	.8					11	3.4		
160–164	2	0.4			18	1.7	1	.2	4	2.0	20	6.3		
165–169	4	.8			18	1.7	2	.3	3	1.5	23	7.2	2	0.5
170–174	4	.8			30	2.9	12	2.1	6	3.0	22	6.9	1	.2
175–179	4	.8	5	2.6	33	3.2	14	2.4	10	5.0	25	7.8	1	.2
180–184	8	1.7	7	3.7	33	3.2	30	5.1	15	7.5	36	11.3	1	.2
185–189	7	1.5	6	3.2	39	3.7	37	6.3	16	8.0	45	14.1	1	.2
190–194	13	2.7	3	1.6	22	2.1	53	9.1	29	14.5	36	11.3	5	1.2
195–199	24	5.1	8	4.2	42	4.0	46	7.9	37	18.5	15	4.7	3	.7
200–204	34	7.2	9	4.7	43	4.1	34	5.8	29	14.5	8	2.5	1	.2
205–209	38	8.0	12	6.3	68	6.5	36	6.1	10	5.0	20	6.3	5	1.2
210–214	37	7.8	15	7.9	98	9.4	17	2.9	8	4.0	16	5.0	5	1.2
215–219	44	9.3	13	6.8	93	8.9	15	2.6	7	3.5	15	4.7	21	5.0
220–224	54	11.4	21	11.1	84	8.1	25	4.3	2	1.0	10	3.1	40	9.5
225–229	52	11.0	10	5.3	126	12.1	27	4.6	5	2.5	8	2.5	43	10.2
230–234	31	6.5	16	8.4	108	10.4	42	7.2	4	2.0	1	.3	95	22.5
235–239	39	8.2	8	4.2	80	7.7	48	8.2	2	1.0	3	.9	87	20.6
240–244	32	6.8	7	3.7	42	4.0	41	7.0	4	2.0	3	.9	56	13.3
245–249	18	3.8	6	3.2	11	1.1	34	5.8	2	1.0			23	5.5
250–254	11	2.3	8	4.2	7	.7	8	1.4	2	1.0	1	.3	11	2.6
255–259	10	2.1	7	3.7	11	1.1	5	.9					6	1.4
260–264	8	1.7	11	5.8	7	.7	7	1.2					6	1.4
265–269			10	5.3	3	.3	2	.3					3	.7
270–274			6	3.2	4	.4	2	.3					5	1.2
275–279			1	.5	5	.5	3	.5					1	.2
280–284			1	.5										
285–289														
290–294														
295–299														
300–304					1	.1								
305–309														
310–314														
Total frequency	474		190		1,041		585		200		320		422	
Number of samples	6		4		17		11		3		9		4	

Length in millimeters	McClure Bay		Dogfish Bay		Shuyak Strait				Kachemak Bay				Russian Harbor [1]	
	1927		1925		1925		1926		1926		1927		1925	
	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent
100–104														
115–119														
120–124														
125–129									3	0.4				
130–134									1	.1				
135–139														
140–144									1	.1				
145–149														
150–154														
155–159														
160–164														
165–169									1	.1				
170–174														
175–179														
180–184	2	1.0												
185–189	2	1.0							1	.1				
190–194	2	1.0												
195–199	1	.5									2	0.6		
200–204	2	1.0									5	1.4		
205–209	13	6.5							6	.9	6	1.7		
210–214	5	2.5							5	.7	12	3.4		
215–219	9	4.5			1	0.6			6	.9	27	7.7		
220–224	9	4.5	1	1.0	1	.6	1	0.9	4	.6	27	7.7		
225–229	12	6.0							6	.9	34	9.7		
230–234	17	8.5	1	1.0	2	1.1	1	.9	6	.9	27	7.7		
235–239	27	13.5	2	2.0	4	2.2	5	4.7	11	1.6	23	6.6		
240–244	37	18.5	2	2.0	8	4.4	2	1.9	15	2.2	17	4.9		

[1] Gill netted, other samples purse seined.

TABLE 31.—*Length frequencies of summer herring*—Continued

Length in millimeters	McClure Bay 1927 Actual	McClure Bay 1927 Per cent	Dogfish Bay 1925 Actual	Dogfish Bay 1925 Per cent	Shuyak Strait 1925 Actual	Shuyak Strait 1925 Per cent	Shuyak Strait 1926 Actual	Shuyak Strait 1926 Per cent	Kachemak Bay 1926 Actual	Kachemak Bay 1926 Per cent	Kachemak Bay 1927 Actual	Kachemak Bay 1927 Per cent	Russian Harbor 1925 Actual	Russian Harbor 1925 Per cent
245–249	26	13.0	4	4.0	6	3.3	3	2.8	17	2.5	15	4.3	1	1.0
250–254	16	8.0	12	12.0	15	8.3	6	5.7	29	4.3	11	3.1	3	2.9
255–259	10	5.0	9	9.0	15	8.3	10	9.3	38	5.6	14	4.0	7	6.6
260–264	3	1.5	28	28.0	18	10.0	9	8.4	46	6.8	19	5.5	14	13.3
265–269	3	1.5	19	19.0	28	15.6	13	12.1	79	11.6	20	5.7	12	11.4
270–274	2	1.0	18	18.0	29	16.1	19	17.7	104	15.3	25	7.1	14	13.3
275–279	1	.5	2	2.0	23	12.8	12	11.2	125	18.4	21	6.0	11	10.5
280–284	------	------	1	1.0	14	7.8	9	8.4	91	13.4	20	5.5	12	11.4
285–289	1	.5	1	1.0	4	2.2	3	2.8	43	6.3	16	4.1	7	6.6
290–294	------	------	------	------	8	4.4	12	11.2	22	3.2	5	1.4	16	15.2
295–299	------	------	------	------	3	1.7	1	.9	10	1.5	2	.6	3	2.9
300–304	------	------	------	------	------	------	1	.9	5	.7	2	.6	3	2.9
305–309	------	------	------	------	------	------	------	------	2	.3	------	------	2	1.9
310–314	------	------	------	------	1	.6	------	------	2	.3	------	------	------	------
Total frequency	200	------	100	------	180	------	107	------	679	------	350	------	105	------
Number of samples	6	------	1	------	4	------	3	------	6	------	11	------	1	------

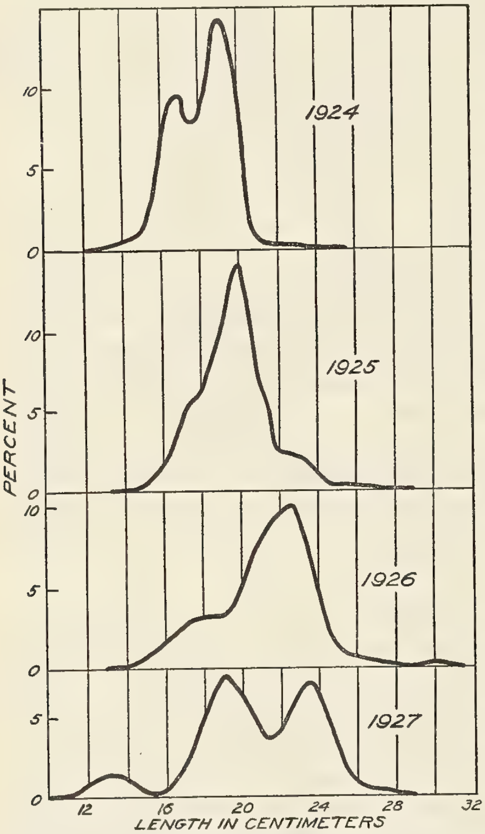

FIGURE 35.—Length frequency distributions for the summer herring of Elrington Passage and immediate vicinity from 1924 to 1927

The lengths were first grouped in half-centimeter categories and then smoothed twice by three's to remove minor modes due to chance sampling. (Fig. 35.) These smoothed length distributions reveal a shifting of sizes from year to year, the mode shifting from 20 centimeters in 1925 to just over 22 centimeters in 1926. This same mode appears to have shifted to 23.5 centimeters in 1927. The bimodal distribution of 1924 suggests that the single mode of the later years is composed of at least two age groups. The mode at 19 centimeters in 1927 appears at 17 centimeters in 1926. This group is numerous enough in 1927 to cause the mode at 23.5 centimeters to appear relatively less important than in the previous year. Some of the modes are no doubt partly concealed, others distorted or exaggerated by various factors, but, nevertheless, these factors are not sufficient to seriously obscure the presence of a dominant size group and its progression through the commercial catch.

Although the data in this form show well the dominance and progression of certain size groups, yet they do not show the relative lack of certain size groups, not only as compared to the other sizes for the same year but as compared to the average of the same sizes over the entire period of four years. The average curve for these four years was obtained by summing the weighted frequencies (percentage

frequencies) of each of the four yearly curves and dividing by four to get the arithmetic mean for each ordinate. (Fig. 36, top curve.) With this average curve as a base, the deviations of each of the four years from the average curve were plotted so that frequency greater than the average appears above the line (as solid black), less than the average below the line.

Figure 36 shows more clearly than Figure 35 the progression of sizes through the commercial catch from small fish (roughly 16 to 19 centimeters) in 1924 to large fish (roughly 22.5 to 25.5 centimeters) in 1927. It shows even more clearly the progression of a poorly represented size group, which, commencing at 15–17 centimeters in 1925, moves to 17–20 centimeters in 1926, and to 18.5–21.5 centimeters in 1927. The group between 17 and 21 centimeters in 1927 appears from the size distributions of Figure 35 to be of great importance, but Figure 36 shows it to be below the averages for those sizes, while the group from 11 to 15 centimeters in 1927 appearing from the size frequencies to be unimportant is shown by Figure 36 to deviate almost in its entirety above the average frequency for the four years.

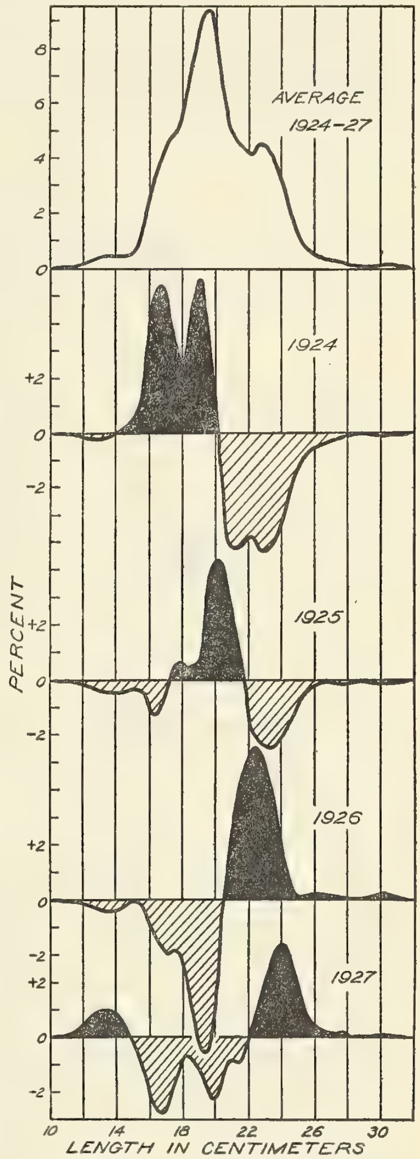

FIGURE 36.—Deviations of the length frequency distributions of each year from 1924 to 1927 from the average of the four years for summer herring of Elrington Passage and immediate vicinity

The view that the progression of sizes in Elrington Passage is due to the growth of fish of dominant age groups is sustained by age analyses. (Fig. 37, Table 32.) The age histogram for 1925 represents only a small portion of the fish in the length distribution, but those for 1926 and 1927 are quite representative. The shift of the 1919 and 1920 year classes from 4 and 5 years of age in 1925 to 6 and 7 years of age in 1927 is very apparent. While there is undoubtedly a small percentage of error in the age readings yet they are of great value in interpreting the significance of the size modes, and the consistency of the results obtained by the two methods is further evidence of their validity.

Eshamy Bay and McClure Bay, about 10 miles apart, show no racial differences, so their length and age distributions have been compared for 1926 and 1927. (Figs. 38 and 39.) Both of the length frequencies present very distinct and sharply defined modes, the 1926 Eshamy Bay mode being at 23 centimeters and the 1927 McClure Bay mode at 24 centimeters, a forward progression of 1 centimeter. The

age histograms show that this shifting in the length mode was due to the growth of the dominant 1920 year class, which was 6 years old in 1926 and 7 in 1927.

The age frequencies presented in Table 32 show that in no case is there a symmetrical distribution of ages around a mode, such as one would expect to find in a population in which the annual increments of new members were about equal. In fact, very unequal proportions of different age groups seems to be the rule. Therefore, it is safe to conclude that our data demonstrates conclusively that dominant year classes are ordinarily present in the Alaska herring.

TABLE 32.—*Frequency at each age*

Age (years)	San Diego, December, 1926		Stephens Passage, January, 1928		Larch Bay, August, 1927		Halibut Cove, gill netted, April, 1926		Halibut Cove, beach seined, April, 1926		Dogfish Bay, August, 1925		Lower Kachemak Bay, August, 1926		Shuyak Strait, July, 1925	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1									24	7.1						
2			9	4.9					66	*19.4*			5	2.0		
3			22	*11.9*					64	*18.8*			3	1.2		
4	1	2.2	9	4.9	12	19.0			79	*23.2*			5	2.0	1	0.7
5			109	*59.2*	20	*31.8*	2	2.2	31	9.1	1	1.2	14	5.7	2	1.3
6	4	8.7	4	2.2	15	23.8	1	1.1	10	2.9	1	1.2	30	*12.2*	4	2.7
7	35	76.1	3	1.6	8	12.7	31	*34.8*	22	6.5	3	3.5	9	3.7	28	*18.8*
8			6	3.2	5	7.9	33	*37.1*	22	6.5	3	3.5	55	*22.4*	18	*12.1*
9	6	13.0	13	7.0	2	3.1	4	4.5	4	1.2	8	9.4	58	*23.7*	7	4.7
10			4	2.2			11	*12.4*	8	2.4	43	*50.6*	12	4.9	63	*42.3*
11			2	1.1			6	6.7	8	2.4	22	*25.9*	14	5.7	20	*13.4*
12			2	1.1	1	1.6	1	1.1	2	.6	4	4.7	33	*13.5*	4	2.7
13			1	.5									5	2.0	1	.7
14															1	.7
15													1	.4		
16																
17													1	.4		
Total	46		184		63		89		340		85		245		149	

Age (years)	Shyak Strait, July, 1926		Elrington Passage, July and August, 1925		Elrington Passage, June and July, 1926		Elrington Passage, June and July, 1927		Eshamy Bay, September, 1926		McClure Bay, September, 1927		Dutch Harbor, August, 1928	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1														
2							21	4.9			1	0.6		
3			13	7.9	35	9.0	13	3.0	4	2.2	1	.6	1	1.2
4	1	1.3	42	*25.5*	137	*35.4*	207	*48.4*	17	9.5	30	17.6		
5	6	7.9	59	*35.8*	82	21.2	52	*12.1*	27	15.2	31	18.2		
6	10	*13.2*	11	6.7	120	*31.0*	38	8.9	114	*64.1*	23	13.5	58	*68.2*
7	2	2.6	11	6.7	3	.8	78	*18.2*	6	3.4	68	*40.0*	16	18.8
8	16	*21.0*	6	3.6	3	.8	2	.5	1	.6	1	.6	4	4.7
9	16	*21.0*	4	2.4	1	.3	9	2.1	1	.6	7	4.1		
10	3	3.9	9	5.5	1	.3	4	1.0	2	1.1	6	3.5	4	4.7
11	6	7.9	10	6.1	3	.8	3	.7	1	.6	1	.6		
12	13	*17.1*			2	.5	1	.2	5	2.8			2	2.4
13	1	1.3									1	.6		
14	2	2.6												
Total	76		165		387		428		178		170		85	

OCCURRENCE OF DOMINANT YEAR CLASSES

Whether the conditions that cause certain year classes to survive in unusual numbers are entirely fortuitous or whether these conditions recur in cycles, is a question. Linked with this comes the question as to the effect the spawning of a dominant year class will have on the stock of the following years. Gilbert and Rich (1927) found that in the Karluk River the red or sockeye salmon (*Oncorhynchus nerka*) presents 5-year cycles. Quoting:

> The graph shows clearly the cyclic character of the runs of red salmon in the Karluk River. Since the Karluk salmon are predominantly 5-year fish, we anticipate a correlation between the run of any year and that of the fifth year preceding, the fifth year following, etc. * * * If it

can safely be assumed that spawning escapements are in the main roughly proportional to the catch, it becomes apparent that they are the predominating factor in determining the size of the runs.

In the salmon, which spawn but once in a lifetime, such a correlation between spawners and offspring is easier to trace than with a fish that may spawn several times during its life. However, Jensen (1927) has attempted to trace just such a correlation in the case of the South Baltic autumn herring, a single local race of herring around Bornholm, spawning in September and October. He found that the catch anomalies (per cent from normal) of the herring fishery at Bornholm showed fluctuations covering three or four years. During 26 years he noted seven fluctuations averaging 3.7 years. Jensen says:

> The periodicity is to be explained as a consequence of the varying amount of fry produced by the varying number of spawning herrings. The Baltic herring generally matures in its third year and the shoals of spawning herrings accordingly consist of fish 3 years old and more. As the herrings of the year classes III and IV in the Baltic greatly predominate over the older year classes, and therefore as a rule produce the largest quantity of fry, the observed periodicity can be explained in this way.

On the other hand the great fishery for the Atlanto-Scandian spring herring shows violent fluctuations due to dominant year classes that appear at irregular intervals (Lea, 1924), seemingly without regard to the number of spawners present.

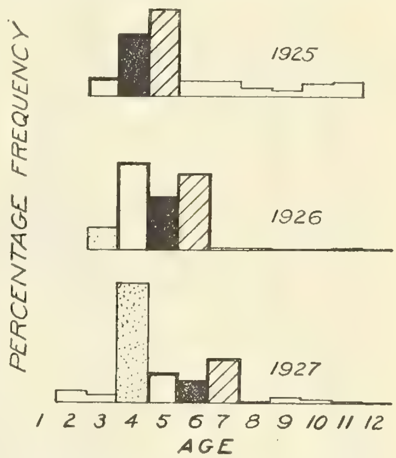

FIGURE 37.—Age histograms of Elrington Passage, Prince William Sound, for 1925, 1926, and 1927

Even in the case of a clear-cut periodicity as in the Karluk salmon, or of a lesser correlation as in the salmon of the Gudenaa (Jacobsen and Johansen, 1921, p. 12–15), it would seem that, owing to the fact that the salmon do not all return to their native stream the same number of years after leaving it (in the Karluk about 85 per cent return at 5 years of age and 10 per cent at 6 years of age), in a comparatively limited number of years the effect of the spawning of a dominant year class would be so distributed that soon its successors in the 5-year cycle would no longer be dominant. That such is not the case causes one to ask if there may not be some other condition present, possibly meteorological, that favors such a 5-year cycle.

If the dominant year classes in the Alaska herring recur in regular cycles, as in the Bornholm autumn herring, then the trend of the fishery should not be hard to establish; but if they recur at irregular intervals, and if successive dominant year classes are of greater or lesser dominance, as in the Norwegian spring herring, then the solution may be more difficult.

EFFECT OF DOMINANT YEAR CLASSES ON THE CATCH

The presence of dominant age groups may have a far-reaching effect; at times a race may be exceedingly abundant and at other times exceedingly scarce, for there may be periods of several years between dominant year classes, the population becoming much reduced before another dominant year class appears in the catch. The appearance of such a year class may cause excessive abundance for a time. When a very dominant year class first enters the commercial catch its members will

be small, lowering the average size of the fish in the whole catch. Later, as the fish of this year class grow older, the average size of the fish in the commercial catch will be gradually raised, until another dominant year class appears and temporarily lowers it. Evidence of such changes in size, due to the progression of dominant year classes, is shown in Elrington Passage by accurate records kept by one of the packers, giving the proportion of the catch pickled each year and the trade categories, according to the size of the fish. To make each year comparable the records have been compared for the month of July:

Year	Number barrels	Per cent pickled	Per cent matjes	Per cent medium	Per cent large
1924	8,125	10.0	71.5	14.4	14.1
1925	4,355	9.3	56.6	25.6	17.8
1926	3,239	15.9	----------	90.9	9.1
1927	2,271	29.1	13.2	77.6	9.2

Matjes are herring from about 9½ to 10½ inches in total length (197–215 millimeters in body length); mediums from about 10½ to 11½ inches in total length (215–232 millimeters in body length); large from about 11½ to 12½ inches or over (232–249 millimeters in body length). Of course, the proportions of each kind pickled will depend to some extent on market conditions, and the sizes included under each name will fluctuate slightly from year to year, but, in the main, the proportion of the catch pickled and the percentage of each class will depend on the raw material available. There are two features so pronounced as to appear valid; one is the increase in the total amounts pickled in 1926 and 1927, the other is the shift in sizes pickled. These changed from over 70 per cent matjes and 14 per cent mediums in 1924 to no matjes and over 90 per cent mediums in 1926. In 1927 the percentage of mediums packed is less than in 1926 owing to the packing of 13 per cent of matjes, but the percentage of the total catch pickled as mediums in 1927 is actually greater than in 1926 and the same is true of the large.

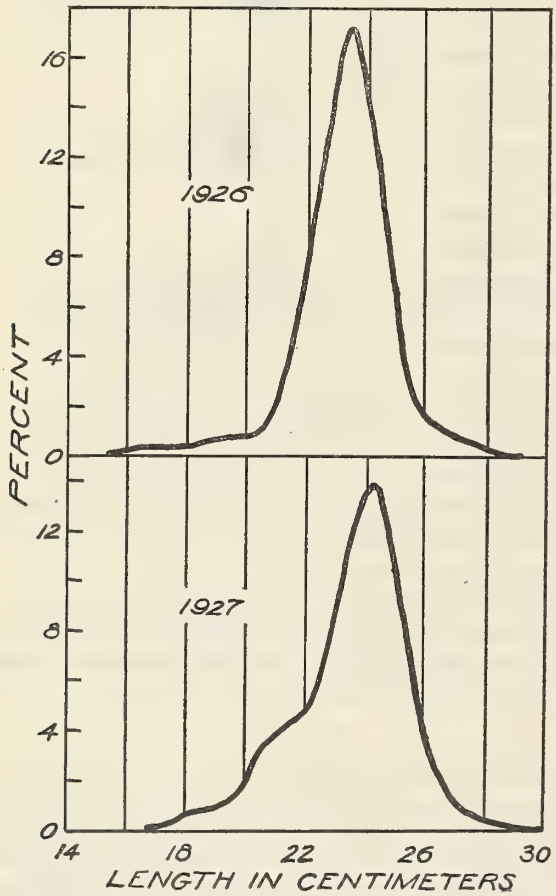

FIGURE 38.—Length frequency distributions for the Eshamy Bay and McClure Bay fall herring for 1926 and 1927, respectively

Comparing these annual changes in the sizes and amounts pickled with the percentage of herring at each size as shown in Figure 35 the existence of a rough correlation is at once apparent, lending support to our biological findings, and thus demonstrating an important point; namely, that the effect of the progres-

sion of sizes due to the growth of dominant year classes, as shown by our sampling, is reflected in the commercial catch.

DOMINANT YEAR CLASSES SHOW RELATIONSHIP OF AREAS

In nearly every case the age distributions of any two localities differ considerably in the proportions of fish of each year class. Thus the age frequencies of Elrington Passage show no similarity to those of samples taken farther to the westward, and the dominant year classes may well be different. This lack of agreement in most cases may be due to different physical conditions in each locality at the time of spawning, although the correlation of these dominant age groups with the physical conditions is far in the future. While this lack of agreement may possibly be wholly environmental in cause, it indicates the lack of migration between stocks of different localities. Indeed, the age frequencies differ between all localities, for which ages have been read, which are shown to be racially distinct (see Independence of Areas p. 272), thus corroborating the evidence of lack of migration between certain stocks set apart by the investigation of their structural differences.

There is a slight possibility that this lack of agreement between the age frequencies in different localities might be due largely to chance. That the reverse is true is strongly suggested by a comparison of the 1926 age frequencies of the summer herring of Shuyak Strait and Kachemak Bay. (Fig. 40, Table 32.) The Shuyak Strait samples were caught on July 15 and the Kachemak Bay samples from August 25 to 28, about six weeks later. Herring were caught in Shuyak Strait for two days following the opening of the season on July 15 and then disappeared, so that it is quite possible that the Kachemak Bay samples came from the same school.

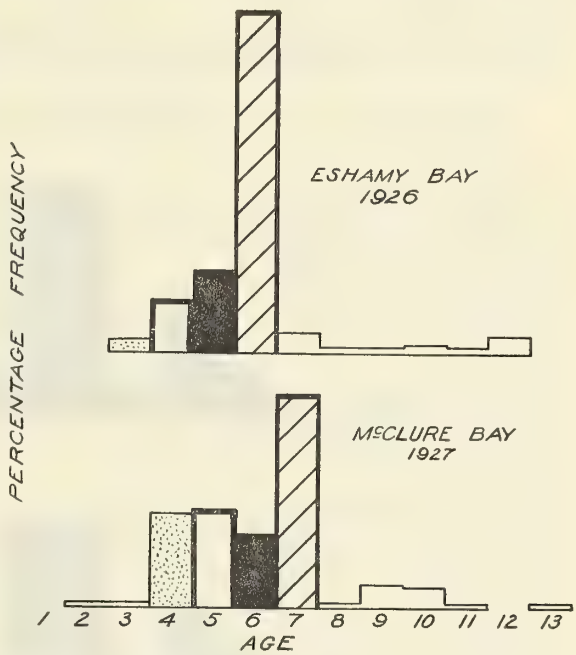

FIGURE 39.—Age histograms of Eshamy Bay, 1926, and McClure Bay, 1927

Assuming that the sampling was truly random and the age readings correct, a mathematical means of testing the significance of the similarity exists, and a measure of judging the probability that two frequency distributions are samples of the same population may be obtained by the formula:

$$\chi^2 = N_1 N_2 S \left\{ \frac{\left(\frac{f_1}{N_1} - \frac{f_2}{N_2}\right)}{f_1 + f_2} \right\} \qquad \text{(Pearson, 1914)}$$

where f_1 is the frequency in a given class of one frequency distribution and f_2 is the frequency in the corresponding class of the other frequency distribution. N_1 and

N_2 are the total number of items in the respective frequencies. S is the summation of these values for each class.

The probability, P, that chance alone would cause the same or a greater divergence between two random samples of the same population is obtained by the formula:

$$P=\epsilon^{-\frac{1}{2}\chi^2}\left(1+\frac{\chi^2}{2}+\frac{\chi^4}{2\times 4}+\frac{\chi^6}{2\times 4\times 6}+\cdots\cdot+\frac{\chi^{y-3}}{2\times 4\times 6\times\cdots\cdot\times(y-3)}\right)$$

where y equals the number of classes, and ϵ equals the base of the Napierian system of logarithms.

From the calculation we obtain P as 0.621, meaning that the age frequencies of 6 out of every 10 samples of the same population would differ as much as these two frequencies.

Application of the formula to the size frequencies gives a value for P of 0.0898, quite different from that of the age readings. This may be due to erroneous age

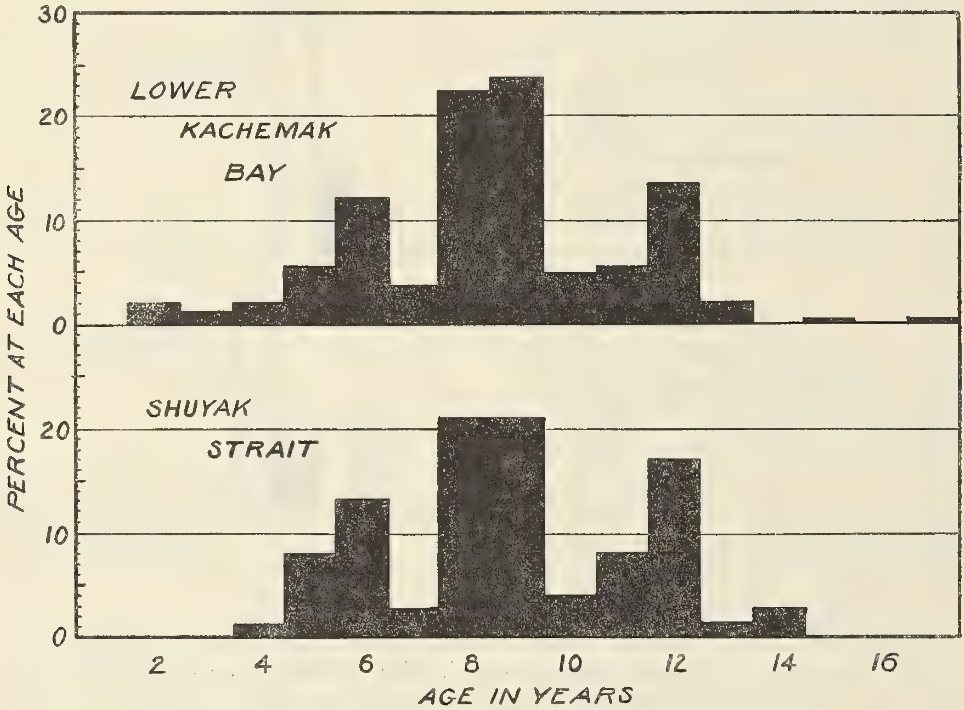

FIGURE 40.—Age histograms of Shuyak Strait and lower Kachemak Bay for 1926

readings or to chance, but an examination of the length frequencies (Table 31) causes one to believe that it is largely due to growth as the two frequencies are very similar, the chief difference being that the modal length in Kachemak Bay is half a centimeter greater than in Shuyak Strait. As mentioned above the Kachemak Bay samples were taken six weeks later than those of Shuyak Strait. The period thus covered, from July 15 to about August 27, is one in which the herring make a large part of the season's growth. These facts could account for the half centimeter difference in modal length, which would cause P to be very low, whereas without the growth in the period intervening between the collection of the samples P would undoubtedly be much higher.

The racial analysis shows that these two localities do not differ significantly in any of the characters compared, their condition factors (Table 29) follow almost exactly the same trend, and their rates of growth (Table 28) are comparable, so there is no reason for supposing them to be separate stocks.

CONCLUSIONS

1. Owing to the short periods during which samples are obtainable from one locality, the proof of the validity of sampling must be placed largely upon the repeated occurrence of consistent variations.
2. Dominant year classes are normally present.
3. The progression of sizes due to the growth of dominant year classes is reflected in the commercial catch.
4. The similarity or difference between the dominant year classes in two adjacent localities gives indications for or against the independence of the two populations.

ANALYSIS OF CATCH STATISTICS

SOURCES OF STATISTICS

The statistics which have been used in studying the changes in abundance have been derived from a number of fairly reliable sources. For the very early years of the fishery (previous to 1904) we have had to rely wholly on published records. Moser (1899 and 1902) and the United States Senate (1912) published the best records of the Killisnoo plant, and Cobb (1906) summarized all of the early records obtainable.

Since 1904 the Bureau of Fisheries has required every individual or company fishing in Alaska to make a sworn annual return of the total amounts and kinds of fishery products prepared, and of the amounts, kinds, and value of fishing gear, boats, and other apparatus used. These sworn returns constitute one of the main sources of information. Another major source of information is the annual statistical review and the monthly numbers of the Pacific Fisherman, a trade journal published in Seattle, Wash. Many of the herring companies have kept careful records of their catches for several years, to which we have had access. A fifth source of information, available since 1926, is contained in detailed records giving the amount, date, and location of every catch made by each individual boat. These records are kept by the herring companies on duplicate receipt books issued by the Bureau of Fisheries, a system which we patterned after that planned by Will F. Thompson and used successfully for several years by the Division of Fish and Game of California. These sources have been supplemented by field notes.

TREATMENT OF DATA

The records do not give the quantities of raw herring captured (except in the case of halibut bait), but give the amounts of various finished products prepared. In analyzing the statistics, it was necessary for purposes of comparison that all amounts be put on a common basis. The unit selected was the pound of raw herring as delivered to the plant. Some of the factors used in converting the weights of finished products into the weights of raw herring were more or less empirically determined, which may have allowed some small errors to creep in. However, the advantages of such a method of treatment are obvious, and such errors as may have arisen as a result are too small to have any appreciable effect on the analysis. For the conversion of canned herring into raw, 75 pounds of raw herring have been allowed for every 48 pounds of canned herring. No statistics are available on the

amount of shrinkage undergone in the kippering of the herring prior to canning, but the total shrinkage here adopted is considered to be a very close estimate by one of the packers who has canned about two-thirds of all that has been prepared in this manner in Alaska. Any errors due to inexactness of the conversion factor, will affect only a few years, as the total amount canned was never large except in 1919.

All of the oil and fertilizer produced in southeastern Alaska from 1882 to 1918 were made by one plant at Killisnoo, and the records of the raw herring used are available up to and including 1911. From 1912 to 1920, when this company failed, 44.9 pounds of raw herring were allowed for each gallon of oil, the factor being calculated for the period from 1909 to 1911, inclusive (a new cooker was installed in 1909, United States Senate, 1912). For the rest of southeastern Alaska from 1919 to 1928 (and for the new company that organized to run the Killisnoo plant since 1923) the raw herring used for reduction has been calculated by allowing 50 pounds of raw herring per gallon of oil and 65 pounds of raw herring per pound of fish meal. The two results were then added and divided by two as the meal and oil came from the same fish. These two factors were calculated from careful records kept by the plant at Red Bluff Bay from 1922 to 1927, inclusive. In Prince William Sound the conversion factors used were 61.2 pounds of raw herring per gallon of oil, and 8.25 pounds of raw herring per pound of meal, as calculated from careful records kept from 1923 to 1927, inclusive, by a plant in Evans Bay. The factors vary some from year to year, but it was found that the factors for oil and meal hardly differed in their reliability, the coefficient of variation $\left(V=\frac{100\ \sigma}{\text{Mean}}\right)$ for the oil factor being 0.213; for the meal factor 0.162.

For the pickled products, 20 per cent shrinkage of the raw herring has been allowed in all districts; that is, the finished product must be increased 25 per cent to represent the raw herring actually used in its preparation. (Figs. 41 and 42.) In addition, certain allowances must be made for waste of small herring. No waste is allowed for herring pickled by companies operating reduction units, as this waste is included with the raw herring for the oil and meal. For the other companies varying allowances have been made in the different districts.

The waste allowed in southeastern Alaska previous to 1918 was only 20 per cent as practically all of the herring were cured by the Norwegian method in which quite small herring are used. To allow for this, the amount of raw herring actually used in the finished product was increased another 25 per cent. From 1918 to 1928 the records differentiate between the Norwegian and Scotch cured products. During this period the waste on the Norwegian cure is the same, but 40 per cent waste was allowed on the Scotch cure, which utilizes only the larger fish.

In Prince William Sound accurate records are available for the amounts of raw herring wasted by a company without a reduction plant in 1922 and 1923. In 1922 they wasted 18 per cent; in 1923, 26 per cent; which means that the raw herring actually used for pickling were increased by 22 per cent and 33⅓ per cent, respectively, to allow for waste. All of the packers are agreed that the waste in Prince William Sound was less in 1922 than in any other year, so the 1923 factor was applied to all of the other years. In Prince William Sound, in the later years especially, a portion of the waste of the companies without reduction plants (of which no accurate

FIGURE 41.—Repacking at Dutch Harbor. Brine is being mixed in the large tierce and drawn off through a spigot. The herring that are to be used in filling up the barrels are being washed in the half tierce in the foreground.

FIGURE 42.—Repacking at Dutch Harbor. The herring shrink about 20 per cent in curing and the deficiency is made up by repacking the top of the barrel with herring of the same day's cure

FIGURE 43.—The Schooner *Rosamond*, a floating saltery at anchor behind McDonald Spit, Kachemak Bay

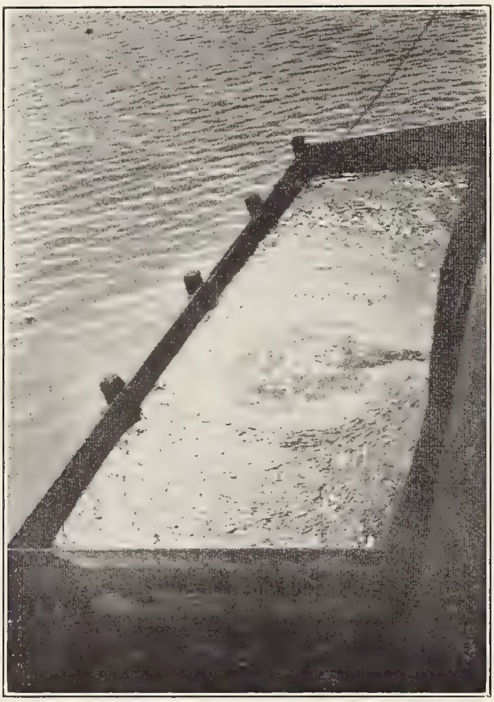

FIGURE 44.—Herring too small to be salted are collected in this manner and dumped outside of the harbor at Halibut Cove, Kachemak Bay. Taken August 24, 1927

records are available) was delivered to the reduction companies to be made into oil and fish meal. This causes a slight error in our calculations, but the amount pickled in Prince William Sound by companies without reduction plants in the later years has been very small. Also it is not an error that will in any way affect our conclusions since it will slightly enlarge the amounts taken in the later years, thus tending to conceal any depletion that may have occurred.

For Cook Inlet the waste on pickled herring up to and including 1923 has been placed at 15 per cent, as determined by a company putting up large packs of pickled gill-net herring in 1921 and 1923. That is, after the pickled product has been increased 25 per cent to allow for the 20 per cent shrinkage in the herring actually pickled, this amount is then increased 17.5 per cent more to allow for the 15 per cent waste. From 1924 up to the present more herring were purse seined than gill netted in Cook Inlet, and 20 per cent has been allowed for waste since purse-seine gear takes a greater proportion of small fish. (Fig. 44.) For all of the localities on Kodiak and Afognak Islands 20 per cent was allowed for waste.

On dry-salted herring 40 per cent was allowed for shrinkage, and, since small fish are used, no allowance was made for waste. No accurate records are available on which to base the actual shrinkage for dry-salted herring, the 40 per cent being more or less arbitrarily decided upon. However, this factor is very nearly correct, and the amounts of dry-salted herring are far too small to affect the results in any manner.

The miscellaneous products are chiefly very small amounts of spiced, kippered, or smoked herring on which 20 per cent has been allowed for shrinkage.

The available data have made it possible to obtain the total net tonnage for the purse-seine fleet in southeastern Alaska. The average was computed for all of the boats for which the tonnages were available, and this average was then multiplied by the total number of boats. The percentages of the fleet for which tonnages were available from 1922 to 1928 are as follows: 1922, 71; 1923, 100; 1924, 65; 1925, 61; 1926, 98; 1927, 91; and 1928, 87 per cent.

ANALYSIS OF FLUCTUATIONS BY LOCALITIES

SOUTHEASTERN ALASKA

The records are incomplete for the years previous to 1910, except for the reduction plant at Killisnoo, for which complete records are available from the time of its founding in 1882 up to the present. From 1910 to 1918 about 50 per cent of the southeastern Alaska catch was taken by this plant and a larger proportion in the earlier years so their records are quite representative of the early catch. (Fig. 45.) The trend in Figure 45 has been obtained by the method of least squares. The changes in the catch have doubtless been influenced by a multiplicity of factors; thus the low point of 1896 coincides with a period of great economic depression, and that of 1888 (not used in determining the trend) with the failure and reorganization of the original company. The fishing effort expended was about equal in the various years. (United States Senate, 1912, p. 15.) The drop of 25.5 per cent in the trend between 1884 and 1920—a period of 37 years—is surely significant and would indicate depletion. It may indicate a considerable degree of depletion whose effects have been concealed by the fishermen seeking new fishing grounds as the older were exhausted.

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The catches of the Killisnoo plant show large variations that may be partially caused by biological factors, such as the passage through the catch of dominant year

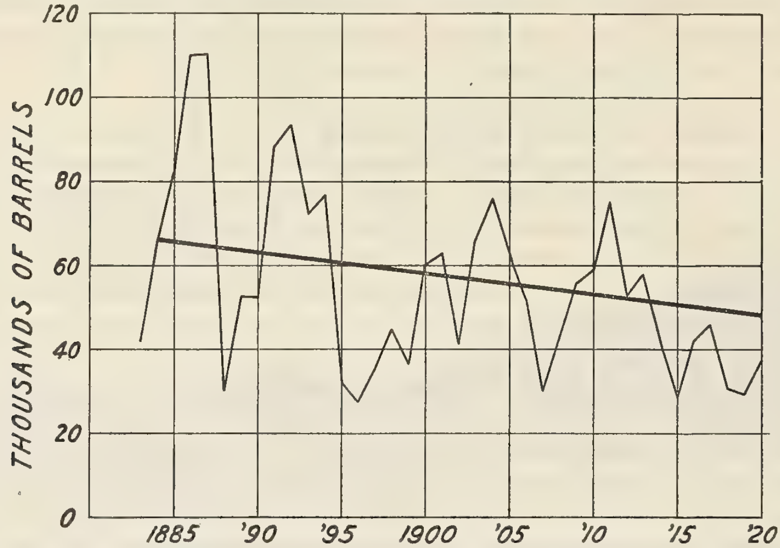

FIGURE 45.—The catch of raw herring by the reduction plant at Killisnoo, on upper Chatham Strait, from 1883 to 1920, inclusive. The trend was obtained by the method of least squares (omitting 1883, because the guano plant was not installed until 1884, and omitting 1888, in which year the first company was reorganized)

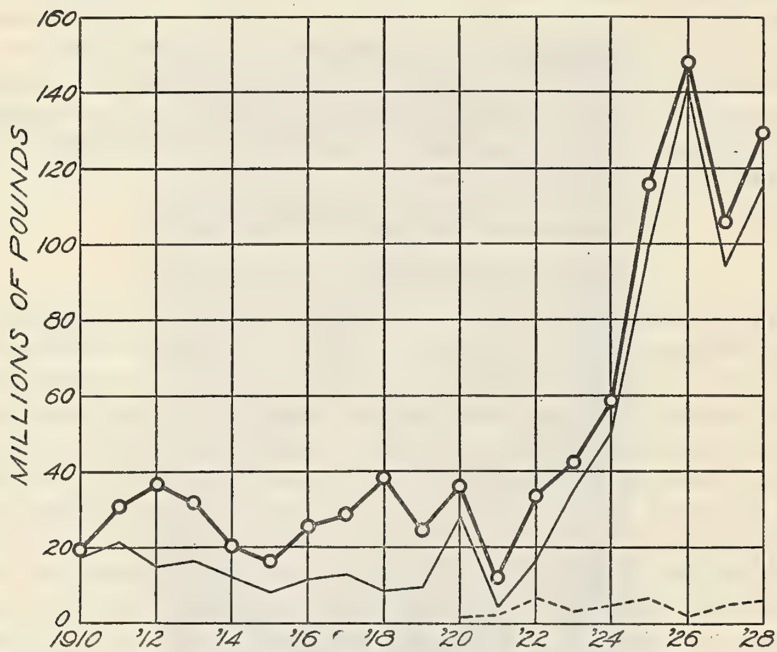

FIGURE 46.—Catch of raw herring in southeastern Alaska from 1910 to 1928, inclusive. Heavy line, total catch. Light line, amount converted into by-products. Broken line, amount pickled by the reduction companies since 1920

groups. But it would be presuming to definitely ascribe any of the changes in the catch to biological factors without an intimate knowledge of the many other factors concerned.

The total catch for southeastern Alaska from 1910 to 1928 is given in Figure 46. As is shown by Table 33 the mode from 1911 to 1913 was caused by dry salting of herring, which was done in Yes Bay, on Behm Canal, near Ketchikan. The failure of this business in 1914 was caused by the dwindling of the herring runs in this vicinity, which does not appear to have been caused by a temporary scarcity, as herring have never been abundant in this locality since that time. The rise from 1916 to 1920 was due to the exploitation of southern Chatham Strait, the introduction of the Scotch method of curing herring aided by war prices, and an attempt to can kippered herring on a large scale. The canning project failed for want of a market, and the pickling industry waned owing to the small size of the southeastern Alaska herring in comparison with those taken in the newly opened Prince William Sound district. These facts, together with a tremendous slump in the herring oil market, are responsible for the drop in 1921 which can in no way be assigned to biological factors.

TABLE 33.—*Pounds of raw herring caught in southeastern Alaska, 1910 to 1928*

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Miscellaneous	Total
1910	11, 780, 000	305, 448	1, 573, 359	76, 152			13, 734, 959
1911	15, 052, 000	743, 496	5, 096, 000	3, 217, 890		4, 000	24, 113, 386
1912	10, 540, 000	1, 130, 376	6, 711, 500	13, 702, 093		51, 000	32, 134, 969
1913	11, 660, 000	912, 512	5, 613, 689	8, 783, 398		21, 714	26, 991, 313
1914	8, 640, 000	1, 150, 198	5, 800, 180	1, 045, 420			16, 635, 798
1915	5, 835, 000	2, 690, 116	5, 403, 410				13, 928, 526
1916	8, 474, 000	7, 586, 480	4, 407, 050	328, 990	1, 488, 750	102, 000	22, 387, 270
1917	9, 236, 000	5, 688, 696	6, 247, 380	25, 050	3, 693, 375		24, 890, 501
1918	6, 170, 000	21, 022, 917	4, 871, 935	1, 169, 000	2, 378, 925	37, 500	35, 650, 277
1919	7, 330, 818	5, 386, 798	3, 284, 455	851, 700	5, 070, 075		21, 923, 846
1920	25, 520, 118	1, 578, 102	5, 525, 500		269, 775	11, 500	32, 904, 995
1921	4, 529, 250	3, 620, 068	3, 875, 048				12, 024, 366
1922	16, 558, 025	14, 314, 926	2, 964, 015			62, 750	33, 899, 716
1923	34, 928, 897	3, 744, 463	3, 807, 139				42, 480, 499
1924	50, 631, 732	4, 409, 372	3, 449, 800	287, 240		12, 000	58, 790, 144
1925	100, 859, 050	6, 903, 483	7, 331, 825	455, 910		12, 750	115, 563, 018
1926	141, 956, 289	2, 014, 577	3, 706, 878			8, 688	147, 686, 432
1927	93, 825, 293	4, 414, 776	7, 413, 655			23, 788	105, 677, 512
1928	117, 552, 660	5, 831, 643	7, 070, 626				130, 454, 929
Total	681, 079, 132	93, 448, 447	94, 153, 444	29, 942, 843	12, 900, 900	347, 690	911, 872, 456

Since 1922 the causes of the fluctuations in the catch may be more readily ascertained owing to the completeness of our records, and the adoption by that date of the power purse-seine boats by all except the Killisnoo and Big Port Walter plants. The catches and the boats of these two plants have been excluded in order that our data might be comparable from year to year. The catches of all of the other reduction plants, the number of purse-seine boats employed, and their total net tonnage have been plotted on a logarithmic scale, so that their rates of change might be readily compared. (Fig. 47.) The number of boats increased at a very slightly lower rate than the catch, but this is to be expected owing to the larger size of the newer boats. The total net tonnage has been plotted so that the catching capacity of the purse-seine fleet may be comparable from year to year. For five years, from 1922 to 1926, the total net tonnage and the catch increased at almost identically the same rate. In 1927 the catch decreased sharply but commenced to rise again in 1928, although at a slightly lower rate than formerly. At the same time the number of boats showed a very slight drop, compensated for by the increase in the net tonnage.

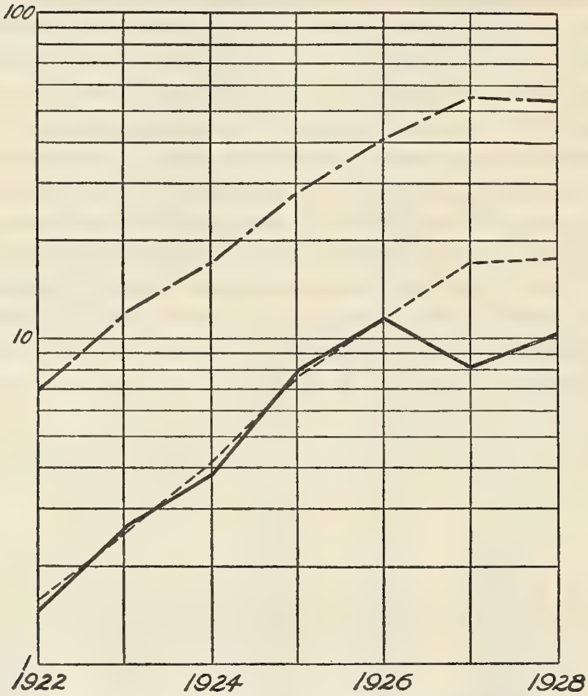

FIGURE 47.—The catch of raw herring and the gear used in . outheastern Alaska from 1922 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Dot and dash line, number of purse-seine boats. Broken line, total net tonnage of the purse-seine boats in hundreds of tons. Solid line, catch of raw herring in tens of millions of pounds

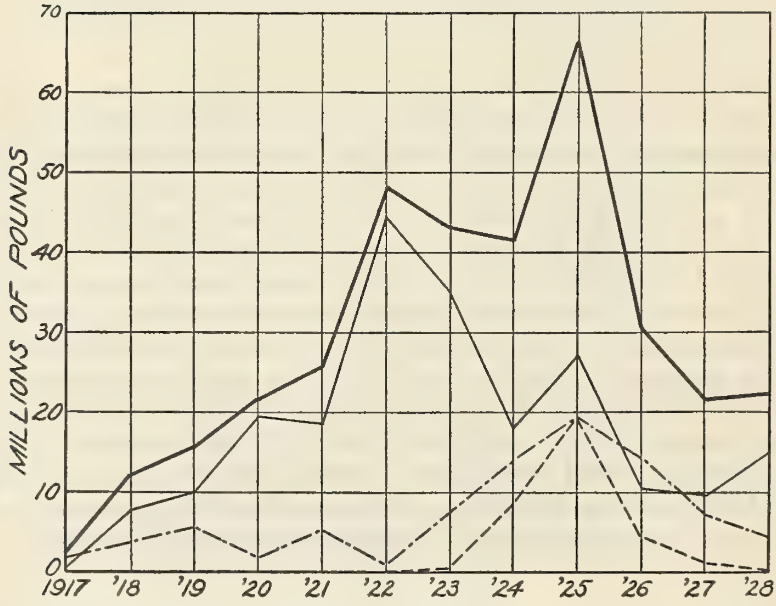

FIGURE 48.—Total catch of raw herring in central Alaska from 1917 to 1928, inclusive. Heavy solid line, total. Light solid line, Prince William Sound. Dot and dash line, Cook Inlet. Broken line, Shuyak Strait

The conclusions are that up to 1926 these statistics of the catch give no evidence of a decline in southeastern Alaska. Since that time the herring have decreased in abundance. Whether this is due to depletion or to a temporary natural fluctuation is not known, but if the catch continues to decline it must be taken as evidence of depletion.

CENTRAL ALASKA

The fishery of central Alaska covers a greater area than that of southeastern Alaska and is more sharply demarked into districts, of which there are three—Prince William Sound, Cook Inlet, and the Kodiak-Afognak Islands. Although these districts are separated from one another by a considerable distance, yet most of the larger operators fish in all three. For this reason the whole area will first be considered as a unit. (Fig. 48, Table 34.) As shown by Figure 48, far the greater part of the c tch has come from Prince William Sound, Shuyak Strait, and Cook Inlet. The simultaneous rise in the Cook Inlet and Shuyak Strait catches in 1924 and 1925 was caused by the expansion of the fishery. Prior to 1923 no one had fished in Shuyak Strait, and the Cook Inlet fishery was limited to gill netting in Halibut Cove.

TABLE 34.—*Pounds of raw herring caught in central Alaska, 1912 to 1928*

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Total
Prince William Sound:						
1917		229, 458	270, 482			499, 940
1918		7, 230, 900	691, 800			7, 922, 700
1919		7, 104, 848	411, 126		2, 565, 300	10, 081, 274
1920	10, 355, 700	9, 185, 591	20, 000		375	19, 561, 666
1921	1, 914, 000	16, 709, 239	12, 000			18, 635, 239
1922	6, 784, 757	37, 145, 225	524, 600			44, 454, 582
1923	13, 854, 488	19, 730, 903	1, 451, 759			35, 037, 150
1924	12, 446, 879	4 216, 023	1, 387, 750			18, 050, 652
1925	17, 117, 594	10, 073, 336	14, 250			27, 205, 180
1926	7, 479, 322	2, 586, 779	712, 550			10, 778, 651
1927	4, 771, 314	4, 379, 418	341, 750			9, 492, 482
1928	13, 863, 218	933, 427	340, 000			15, 136, 645
Cook Inlet:						
1914		311, 346				311, 346
1915		29, 400				29, 400
1916		138, 474				138, 474
1917		1, 886, 745				1, 886, 745
1918		3, 970, 029				3, 970, 029
1919		5, 246, 386	50, 000			5, 296, 386
1920		1, 918, 497				1, 918, 497
1921		4, 587, 576		634, 600		5, 222, 176
1922		606, 890		400, 800		1, 007, 690
1923		7, 455, 105		107, 251		7, 562, 356
1924		11, 551, 371		2, 528, 631		14, 080, 002
1925		18, 049, 333		1, 176, 148	2, 850	19, 228, 331
1926		14, 188, 231		84, 168		14, 272, 399
1927		6, 887, 314	109, 500	184, 535		7, 181, 349
1928		3, 864, 112		440, 045		4, 304, 157
Shuyak Strait:						
1923		397, 800				397, 800
1924		8, 421, 660				8, 421, 660
1925		19, 095, 172	30, 000			19, 125, 172
1926		4, 720, 677	45, 700			4, 766, 377
1927		1, 097, 031	177, 000			1, 274, 031
1928		3, 120				3, 120
Izhut Bay:						
1922		19, 500				19, 500
1924		273, 000				273, 000
1925		808, 470				808, 470
Raspberry Strait:						
1922		563, 745				563, 745
1923		12, 363				12, 363
1927		263, 055				263, 055
Uganik Bay:						
1923		46, 800				46, 800
1924		167, 115				167, 115
1925		29, 578				29, 578
Uyak Bay:						
1917		5, 304				5, 304
1918		33, 384				33, 384
1919		624				624
1920		5, 304				5, 304

TABLE 34.—*Pounds of raw herring caught in central Alaska, 1912 to 1928*—Continued

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Total
Dry Spruce Bay: 1922		30, 615				30, 615
Kizhuyak Bay: 1922		930, 540				930, 540
Vicinity of Kodiak:						
1912			40, 000			40, 000
1916		140, 400				140, 400
1917		270, 504				270, 504
1918		203, 424				203, 424
1919		514, 800	4, 000			518, 800
1920		86, 424				86, 424
1921		194, 688				194, 688
1923		110, 136				110, 136
1924		207, 870				207, 870
1926		21, 645				21, 645
1927		22, 815				22, 815
Shearwater Bay:						
1921		681, 174				681, 174
1922		1, 420, 770				1, 420, 770
1923		75, 855				75, 855
1924		576, 420				576, 420
1925		30, 810				30, 810
1926		573, 885				573, 885
1927		3, 625, 830				3, 625, 830
1928		2, 856, 945				2, 856, 945
Three Saints' Bay: 1926			231, 700			231, 700
Kiavik Bay lagoon: 1921		1, 014, 000				1, 014, 000
1912			40, 000			40, 000
1914		311, 346				311, 346
1915		29, 400				29, 400
1916		278, 874				278, 874
1917		2, 392, 011	270, 482			2, 662, 493
1918		11, 437, 737	691, 800			12, 129, 537
1919		12, 866, 658	465, 126		2, 565, 300	15, 897, 084
1920	10, 355, 700	11, 195, 816	20, 000		375	21, 571, 891
1921	1, 914, 000	23, 186, 677	12, 000	634, 600		25, 747, 277
1922	6, 784, 757	40, 717, 285	524, 600	400, 800		48, 427, 442
1923	13, 854, 488	27, 828, 962	1, 451, 759	107, 251		43, 242, 460
1924	12, 446, 879	25, 413, 459	1, 387, 750	2, 528, 631		41, 776, 719
1925	17, 117, 594	48, 086, 699	44, 250	1, 176, 148	2, 850	66, 427, 541
1926	7, 479, 322	22, 091, 217	989, 950	84, 168		30, 644, 657
1927	4, 771, 314	16, 275, 463	628, 250	184, 535		21, 859, 562
1928	13, 863, 218	7, 657, 604	340, 000	440, 045		22, 300, 867
Total	88, 587, 272	249, 769, 208	6, 865, 967	5, 556, 178	2, 568, 525	353, 347, 150

The number of purse-seine boats and the catch for central Alaska are shown on a logarithmic scale in Figure 49. From 1918 to 1923, inclusive, all of the gill-net

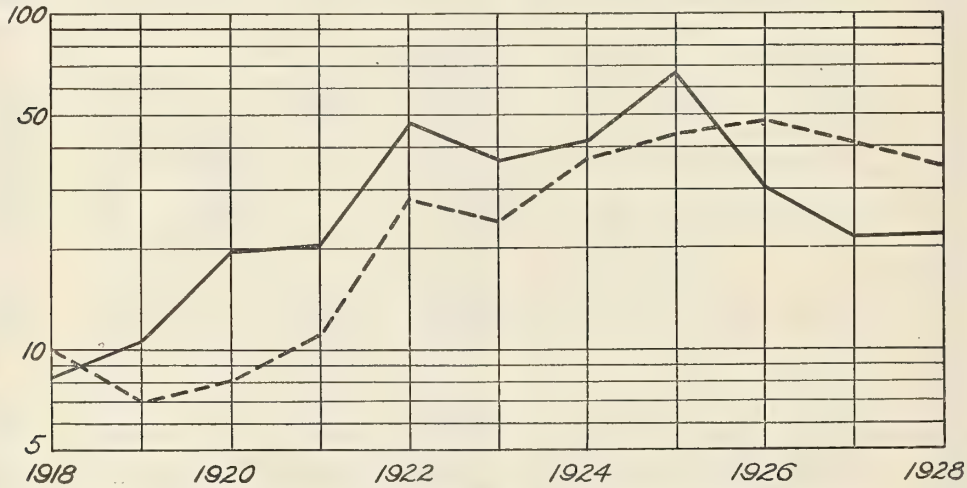

FIGURE 49.—The catch of raw herring and the gear used in central Alaska from 1918 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

catch from Cook Inlet has been subtracted from the central Alaska catch. From 1924 on, the gill-net and purse-seine catch for Cook Inlet can not be accurately segregated, but the purse-seine catch makes up much the greater part, the gill-net portion

being less than in the previous years. However, any slight error in the comparison introduced by the inclusion of this small amount of gill-net catch, being present only since 1924, is an error that will tend to obscure rather than to emphasize any depletion that may have occurred. Up to 1925 the catch increased at a very slightly lower rate than the number of boats, then the catch declined sharply in 1926 and 1927, rising only a trifle in 1928. The fact that the catch declined in spite of the exploitation of new areas suggests depletion.

Prince William Sound.—The fishery of Prince William Sound—the largest producing district in central Alaska—deserves special mention. Figure 48 shows that the total catch rose to a maximum in 1922 and has since declined. Reference to Figure 50, in which the catch, the number of purse-seine boats, and the pickled portion of the catch are plotted on a logarithmic scale shows that the catch and the number of boats increased almost proportionately until 1922, while since that time

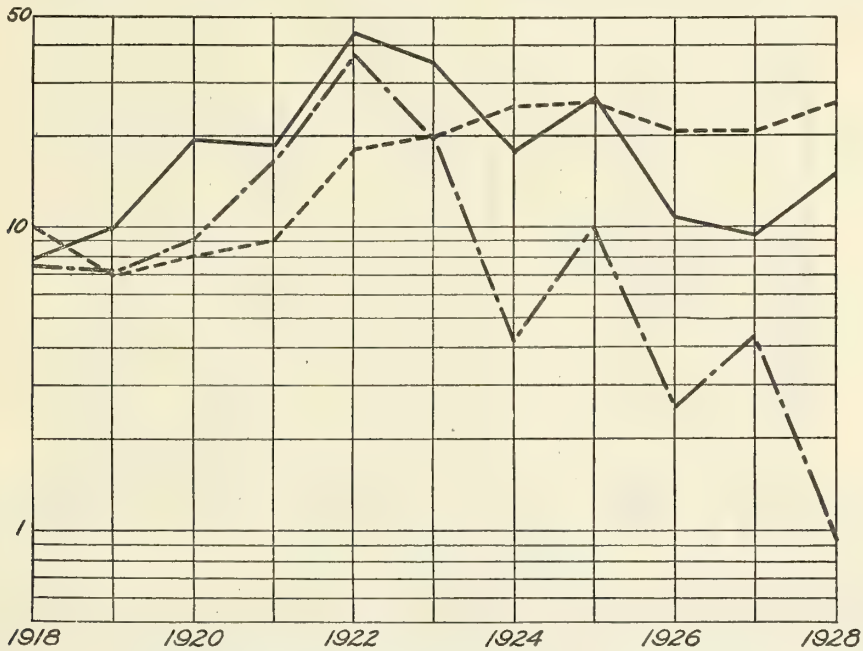

FIGURE 50.—The catch of raw herring and the gear used in Prince William Sound from 1918 to 1928, inclusive, plotted on a logarithmic scale to show the comparative rate of change. Broken line, number of purse-seine boats. Solid line, total catch in millions of pounds. Dot and dash line, portion of catch used for pickling

the number of boats shows a slight increase but the catch has declined rapidly. The low catch per boat in 1918 is undoubtedly due to the fact that nearly all of the Prince William Sound plants were built in that year.

Of far greater importance, however, than the fall in the total catch, is the decline in the amount of the catch used for pickling, since this portion of the catch (composed of fish over 9½ to 10 inches in total length) represents the bulk of the mature spawning population on which the fishery must depend for its continuance. From 1922 to 1928 the amount of herring used for pickling has decreased at the average rate of about 45 per cent per year. Even this does not give an adequate picture of the true significance of the fall unless one remembers that the bulk of the herring pickled in 1926 and 1927 (see figs. 37 and 39) were spawned as early as 1920, and the very small portion of the

catch which was pickled in 1928 was composed largely of herring spawned in 1922 and 1923. Just because fluctuations in the catch may be caused by dominant year classes, it must not be supposed that a very small spawning population is sufficient for the continuance of a prosperous fishery, and the very fact that the success of spawning does vary, makes it more necessary that there be an adequate number of spawners to tide over periods of unfavorable years. Since the offspring of the abundant adult population of the early years were so greatly reduced in numbers before reaching maturity, one can not hope that the small numbers of offspring that will survive to maturity from the spawning of as scarce an adult population as that of 1928 will be sufficient to maintain the fishery.

Cook Inlet.—The analysis of the data in Cook Inlet is complicated by the fact that two methods of fishing are employed, gill netting and purse seining. Previous to 1923 only gill nets were employed, but in that year one purse seine was used, and

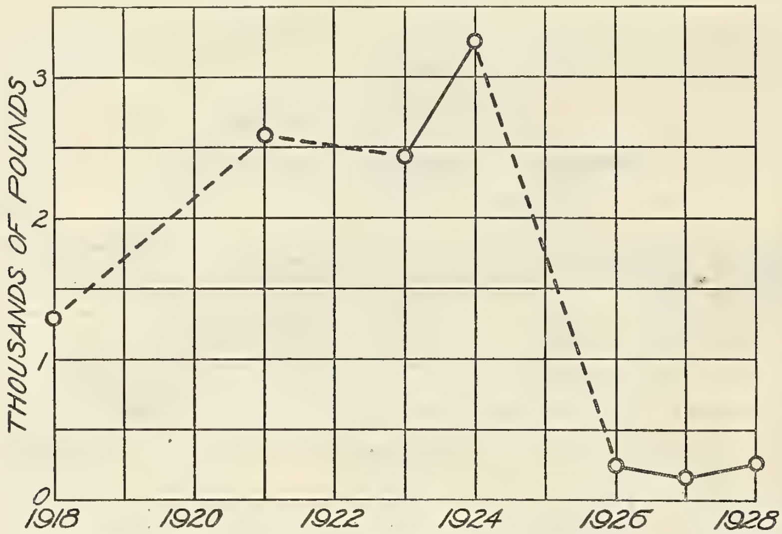

FIGURE 51.—Th catch of raw herring per fathom of gill net in certain years from 1918 to 1928, inclusive, in Kachemak Bay, Cook Inlet

since then gill netting has played a minor rôle. Unfortunately, no records are available which show the total number of gill nets fished each year, or which separate the gill-net and purse-seine catches of those operators employing both methods of fishing. However, there are seven years in which we have accurate records of the fathoms of gill net used by a portion of the operators. For these years the following data are available:

Year	Fathoms of gill net	Pounds of raw herring caught	Year	Fathoms of gill net	Pounds of raw herring caught
1918	1,782	2,313,339	1926	4,370	1,051,932
1921	500	1,293,968	1927	6,110	982,181
1923	450	1,097,355	1928	3,075	795,115
1924	550	1,810,496			

From this has been calculated the average catch per fathom of gill net. (Fig. 51.) Among the earlier years there are records of the gear only in 1918. If this one year is representative of the abundance of that period, there was a considerable rise up to the level of 1921 to 1924. If this rise is valid it can be accounted for by a change

in the gill nets themselves, for during the early years of this fishery the fishermen used chiefly salmon purse-seine web of 3½-inch mesh (stretched measure). Their use at Halibut Cove is mentioned in the Pacific Fisherman as recently as April, 1920. Residents of Halibut Cove say that since that time 3-inch mesh herring gill nets of finer twine were used exclusively. Although the points on the curve for 1921, 1923, and 1924 are not based on many data, yet their close agreement lend them validity. The 1926, 1927, and 1928 points are based on ample data. The fall between 1924 and 1926 would appear to be rather too sudden to be caused by depletion (when the gill-net fishery had kept up so long) were it not for the fact that this is the period when the purse seiners commenced an intensive fishery just outside of Halibut Cove. We must conclude that the gill-net fishery in Halibut Cove presents strong evidence of a decline in the numbers of older fish.

As mentioned above, all of the purse-seine and gill-net catches can not be accurately segregated, but since the great bulk of the take since 1924 has been caught by

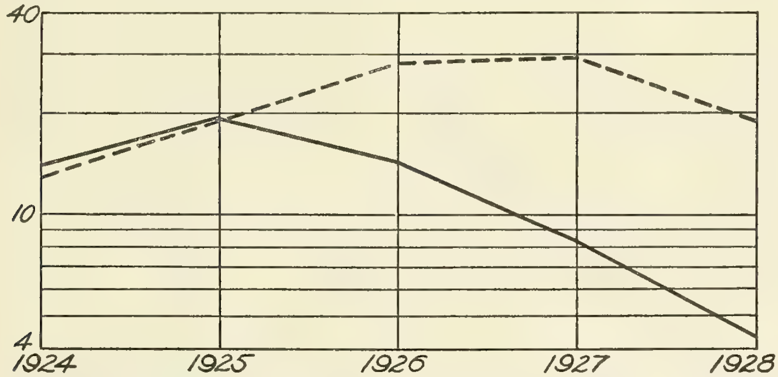

FIGURE 52.—The catch of raw herring and the gear used in Cook Inlet from 1924 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

purse seiners, the rates of change in the total amount of the catch and the number of purse-seine boats have been compared by plotting them on a logarithmic scale. (Fig. 52.) The data for the number of boats is subject to the following minor errors—to plus or minus one boat in 1924 and in 1925, and to the exclusion from the number of boats in 1928 of several that visited the district for short periods and left because of lack of fish. The errors in 1924 and 1925 are too small to be regarded. In 1928 those boats making short stays in the district were excluded so as to allow no personal judgment to creep into the analysis as to which boats could be said to have actually fished in the district. In 1924 and 1925 the boats and the catch increased at practically the same rate. Since then the catch has decreased at an average rate of over 35 per cent each year, while the boats continued to increase until 1927, then decreased between 1927 and 1928 although at a lower rate than the catch. From the evidence afforded by this analysis of the purse-seine catch it must be concluded that the Cook Inlet fishery shows a decline in abundance. This is substantiated, as mentioned above, by the failure of the gill-net fishery.

Shuyak Strait.—For Shuyak Strait the catch and the number of boats are shown in Figure 53. They have not been plotted on a logarithmic scale because it is felt that in this instance the two are proportional only within certain limits. All

of the fishing is carried on in one tiny, sheltered bay, about 1½ miles by 1 mile. Due to the restricted area fished and the ease of impounding there is doubt that, after reaching certain limits, trebling the number of boats would materially affect the catch. During the first two years of the fishery the catch was limited chiefly by the lack of sufficient packing facilities. In 1925 these facilities were taxed to the utmost, but were probably sufficient for nearly the maximum possible pack, since, owing to the ease of impounding, surplus fish could be held for many days and the plants kept constantly busy.

From 1926 on, the facilities have been sufficient for a much larger pack than that of 1925. The drop in the number of boats in 1927 was due to the closure of the waters of Afognak reserve to all but native fishermen, but it can readily be seen

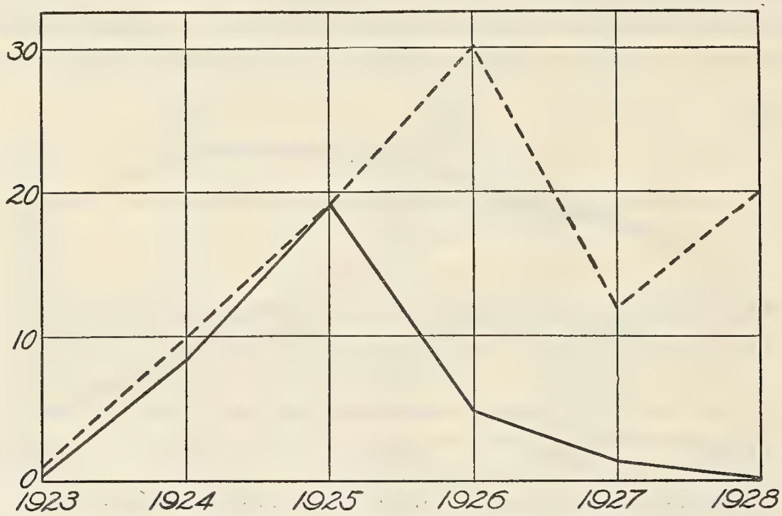

Figure 53.—Catch of raw herring and gear used in Shuyak Strait from 1923 to 1928, inclusive. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

that the number of boats was sufficient for a much greater pack had fish been available. From the catch analysis one must conclude that there has been a tremendous decrease in abundance.

CONCLUSIONS

From the statistical analysis of the catch the following conclusions may be drawn:

1. In southeastern Alaska the abundance remained practically at a level from 1922 to 1926, fell sharply in 1927, but recovered slightly in 1928.

2. In central Alaska as a whole, owing to the exploitation of new areas, the rates of change of the catch and the numbers of boats were similar from 1918 to 1925, but the catch has declined markedly the past three years.

3. In Prince William Sound except for minor fluctuations the abundance has declined progressively since 1922. This fall in abundance has been especially rapid in the larger sizes.

4. In Cook Inlet the fall in the catch per fathom of gill net indicates a tremendous decrease in abundance of at least the larger sizes between 1924 and 1926.

5. In Cook Inlet the abundance, as shown by the comparative rates of change of the catch and of the purse-seine fleet, has fallen steadily since 1925.

6. In Shuyak Strait the catch commenced to decline in 1926 and reached the vanishing point by 1928.

EVIDENCE OF DEPLETION

The results of the statistical analyses, the study of the composition of the catch, and other information give evidence that, in some instances, points to depletion.

One evidence of depletion, the value of which is strengthened by the results of the study of the independence of areas, is the lack of continuity of the fishery in any one locality. The occasional appearance of dominant year classes may serve to explain fluctuations in abundance but hardly explains the scarcity of herring over long periods of years in localities where they formerly were abundant. This condition exists in Kootznahoo Inlet (Moser, 1899), Yakutat (Moser, 1902; Alexander, 1912), and Yes Bay (Bower and Fassett, 1913). That this discontinuity can scarcely be due to migration is shown by the results of the studies on the independence of areas. Depletion would seem to be the logical cause for these declines in abundance.

In the summer fishery of southeastern Alaska the abundance, as shown by the rates of change of the catch and the number of seine boats, decreased sharply in 1927, but recovered somewhat in 1928. However, in 1928 a considerable portion of the pack came from areas 1, 9, 12, and 13 (fig. 8), distant areas scarcely touched by the summer fishery of previous years, so that the decline in abundance shown in 1927 may have actually continued in 1928, although obscured by the exploitation of these more distant areas. Should this decline continue it must be considered as evidence of depletion.

Another possible evidence of depletion in southeastern Alaska is the failure of the amount pickled, consisting of larger fish (fig. 46), to rise in conjunction with the tremendous increase in the total catch. However, there are so many factors involved, economic and otherwise, as to make any conclusions speculative, for in this district the pickling of herring has long been merely an adjunct to the oil and fish-meal industry. The increase in the size of the boats and the spread of the fishery to more distant areas would have much influence on the condition of the fish as received at the plant, perhaps preventing an increase in the amount pickled.

In Prince William Sound the abundance has declined since 1922 with minor fluctuations. This decline has been especially sharp in the pickled portion of the catch, consisting of the larger fish. In this case the decrease in the amount pickled represents a real decrease in the abundance of older fish, as in this area the pickling of herring has always been the major object of the fishery. Although there are minor fluctuations that may be caused by factors which we can not estimate, such as the varying accessibility of the schools, yet the sharp downward trend over a 6-year period gives evidence of depletion.

In Cook Inlet the great decrease in the catch per fathom of gill net since 1924 indicates a decrease in abundance of at least the larger fish. The analysis of the purse-seine fleet shows that during this period both the gill-net and purse-seine catch were decreasing. The age analyses show that there were many year classes present so that the decline in abundance can not be construed as a mere temporary decline due to the passage of dominant year classes. Hence, depletion is believed to have occurred.

In Shuyak Strait the catch commenced to decline in 1926 and had fallen to practically nothing by 1928. The presence of fish of many year classes in the catch indicates that this decrease can not be assigned to the passage of dominant year classes. The decrease in abundance has been so rapid and so great as to cause one to question whether it can be due to depletion, but the concentration of large quantities of gear in the very restricted area fished makes it appear quite probable that such has been the cause.

SUMMARY

The following brief summary is given of the main conclusions reached in this paper:

BIOLOGY

1. The Pacific herring is very closely related to the Atlantic herring.
2. Herring of 1 and 2 years of age occur close inshore. In the summer months they mingle only slightly with the schools of older fish.
3. The schools of mature herring disappear after spawning and reappear in summer. They approach the shore in the fall and remain in close proximity thereto until spawning time.
4. The herring are naturally smaller in the southern part of their range and increase in size toward the north and west, the largest being found along the Alaska Peninsula and in the Aleutian Islands.
5. The existence of separate populations of herring has been demonstrated in California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Prince William Sound, Kachemak Bay-Shuyak Strait, Shearwater Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay. Dogfish Bay herring may also be a distinct stock but more data are needed to confirm this.
6. The herring spawn later in the northern and western portions of their range than in the southern.
7. In Kachemak Bay, central Alaska, 52 per cent of the 3-year olds, 83 per cent of the 4-year olds, and all of the 5-year olds were mature.
8. In Stephens Passage, southeastern Alaska, 84 per cent of the 3-year olds and all of the 4 and 5 year olds were mature.
9. The age of the Pacific herring can be determined with a fair degree of accuracy from the scales.
10. The differences in rate of growth are marked. At 6 years of age the Unalaska herring are 6.5 centimeters longer and 2.8 times heavier than Stephens Passage herring.
11. The date of attainment or loss of sufficient fatness for pickling will vary at least two weeks in different years.
12. The condition (or fatness) attained by any certain date may vary considerably between adjacent localities.
13. The maximum condition attained will vary considerably from year to year.

CONDITION OF THE FISHERY

1. Owing to the short periods during which samples are obtainable from any one locality in central Alaska, the proof of the validity of sampling must be placed largely upon the repeated occurrence of consistent variations.
2. Dominant year classes are normally present.

3. The progression of sizes due to the growth of dominant year classes is reflected in the commercial catch.

4. The similarity or difference between the dominant year classes in two adjacent localities gives indications for or against the independence of the two populations.

5. In southeastern Alaska the abundance of herring remained practically at a level from 1922 to 1926, fell sharply in 1927, but recovered slightly in 1928.

6. In central Alaska, owing to the exploitation of new areas, the rates of change of the catch and the number of purse-seine boats were similar from 1918 to 1925, but the catch has declined markedly in the past three years.

7. In Prince William Sound, central Alaska, except for minor fluctuations the abundance has declined progressively since 1922. This fall has been especially rapid in the larger sizes.

8. In Cook Inlet, central Alaska, both the catch per fathom of gill net and the comparative rates of change of the number of purse-seine boats and the catch show a decline in abundance since 1925.

9. In Shuyak Strait, central Alaska, the catch commenced to decline in 1926 and reached the vanishing point by 1928.

10. The lack of continuity of the fishery in any one locality gives evidence of depletion.

11. There is some evidence of depletion in southeastern Alaska, but the data on hand do not offer sufficient proof.

12. The data indicate severe depletion in Prince William Sound.

13. Depletion has probably occurred in Cook Inlet and in Shuyak Strait.

14. Due to the rapid growth in the third and fourth summers, any certain weight of herring of 2 or 3 years of age is probably more valuable to the species than an equal weight of older fish, indicating that this may be one of the best points in their life history at which to apply protection.

15. It is deemed necessary that additional protection be applied to the herring in the Prince William Sound, Cook Inlet, and Shuyak Strait areas.

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